Navigation Technologies for Future Autonomous Vehicles

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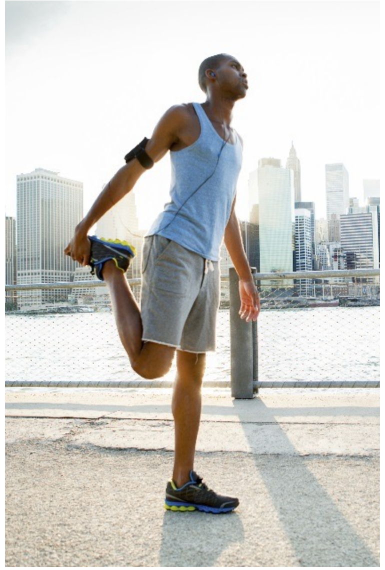
AGENDA

- Status of Current Navigation Markets Technology
- Challenges of Autonomous Navigations
- Pillars of Navigation Technologies
- The Need for Sensors Fusion
- The Potential of Low-Cost Sensors for Autonomous Navigation
- Performance by Examples

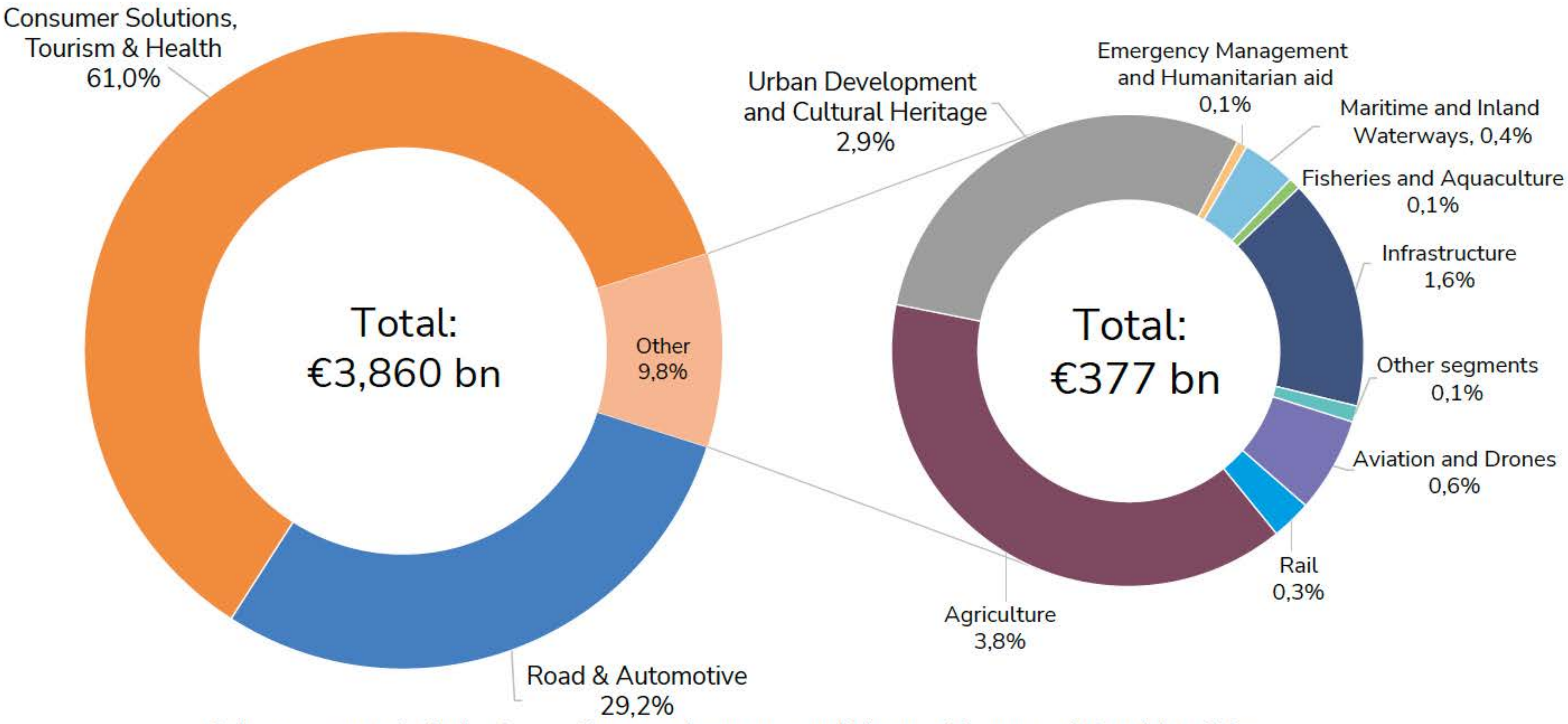
Navigation Sensors in Our Daily Life Activities

Navigation Sensors bring smart, connected devices for many our day-to-day life activities



NAVIGATION MARKETS

Cumulative 10-years Revenue 2020-2030 by segment
Road and Consumer Markets solutions dominate total revenues

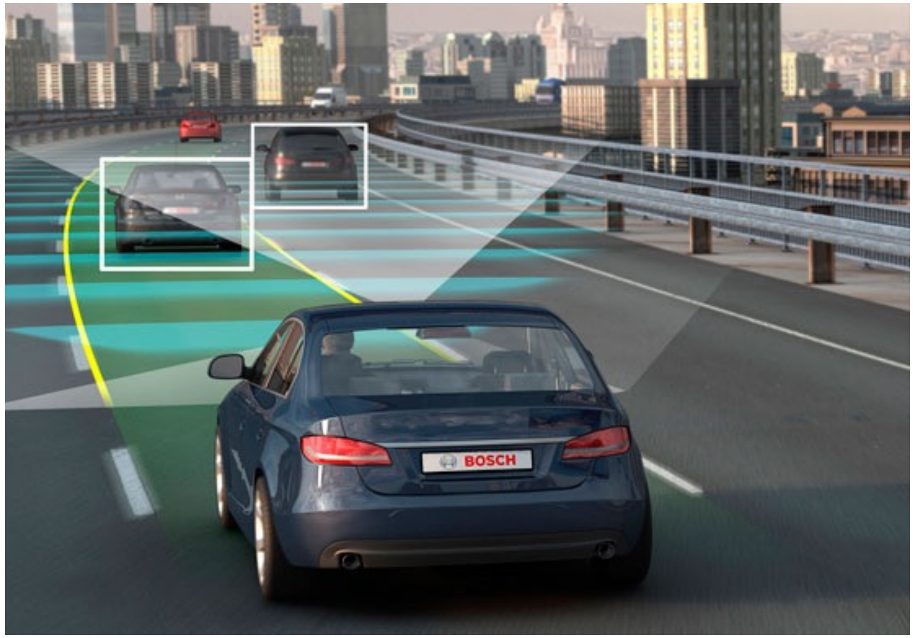


⁺Other segments includes Space, Forestry, Insurance and Finance, Energy and Raw Materials

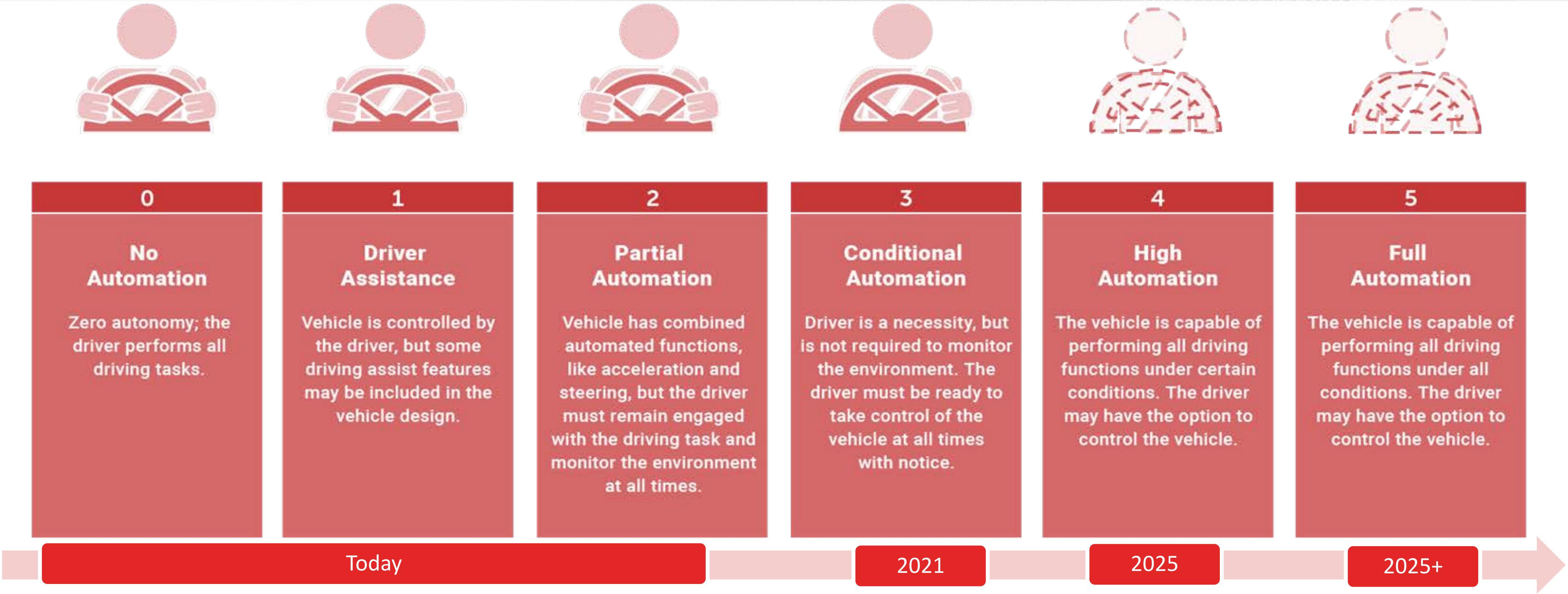
Source: European GNSS Agency (GSA) – EO ad GNSS Market Report | Issue 7, 2022

MAJOR MARKET SEGMENTS

- **Road and Consumer solutions dominate by far all other market segments in terms of cumulative revenue** with a combined total of 93.3% for the forecasting period 2019-2029.
  - **Road sector**, most revenues are generated by In-Vehicle Systems (IVS), ADAS and fleet management, and autonomous cars
  - **Consumer solutions** revenues mainly come from the data revenues of smartphones and tablets using location-based services (is becoming more lucrative with the release of dual-frequency raw measurements on Andriod Devices).



LEVELS OF AUTONOMOUS VEHICLES



- The demand for **precise, continuous, and affordable positioning** is increasing everyday in many applications including **automated vehicle navigation**.
- Currently, level 1 and level 2 automated vehicles are commercially available.
- **Level 2 requires meter-level positioning accuracy on highways and suburban areas**.
- Highway driving includes high-speed dynamics and short **GNSS outages** due to overpasses and other obstacles.

Autonomous Navigation Requirements

Accuracy

- Decimeter level accuracy plus orientation and velocity

Global

- Works everywhere (no base stations)

Starts Anywhere

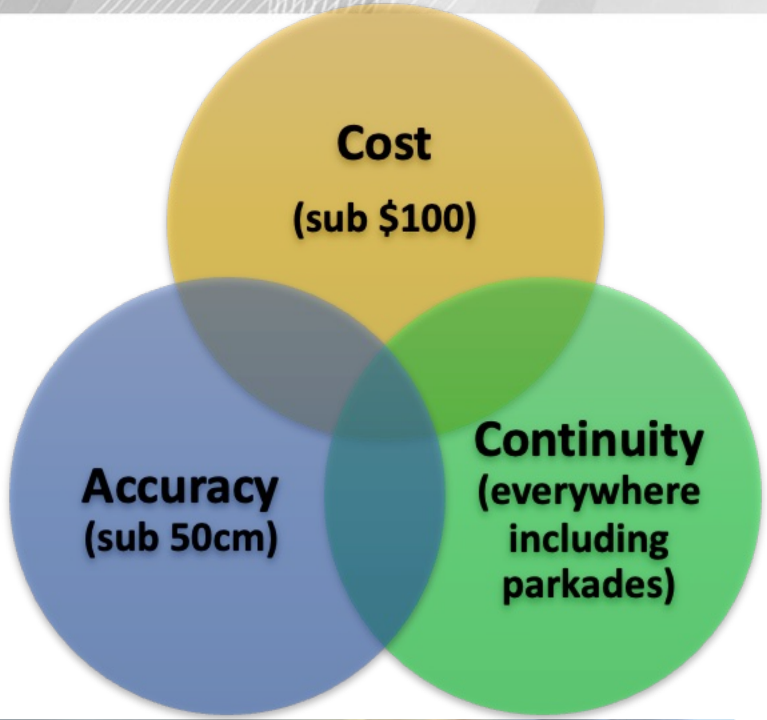
- Even without initial GNSS

Instant

- Resolution <5s

Continuous

- Performs in tunnels, dense urban environments, multi-level highway junctions, and even parkades
- Positional errors without GNSS : <1% of distance travelled



CHALLENGES FOR VEHICLE NAVIGATION SYSTEMS

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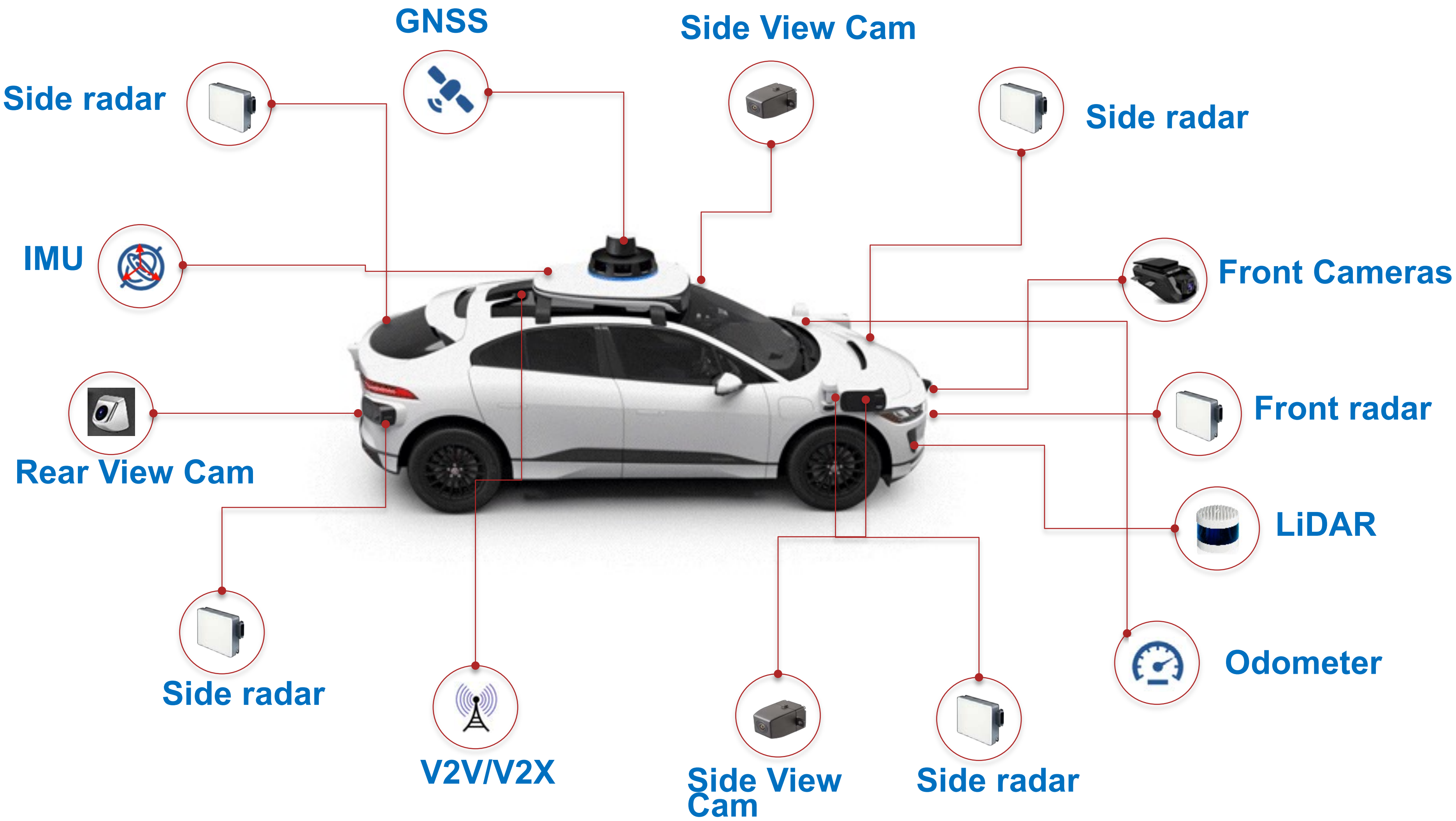
1 High Cost

2 Creating (and maintaining) maps for self-driving cars is difficult work

3 Operation in All Weather

4 Operation Everywhere.

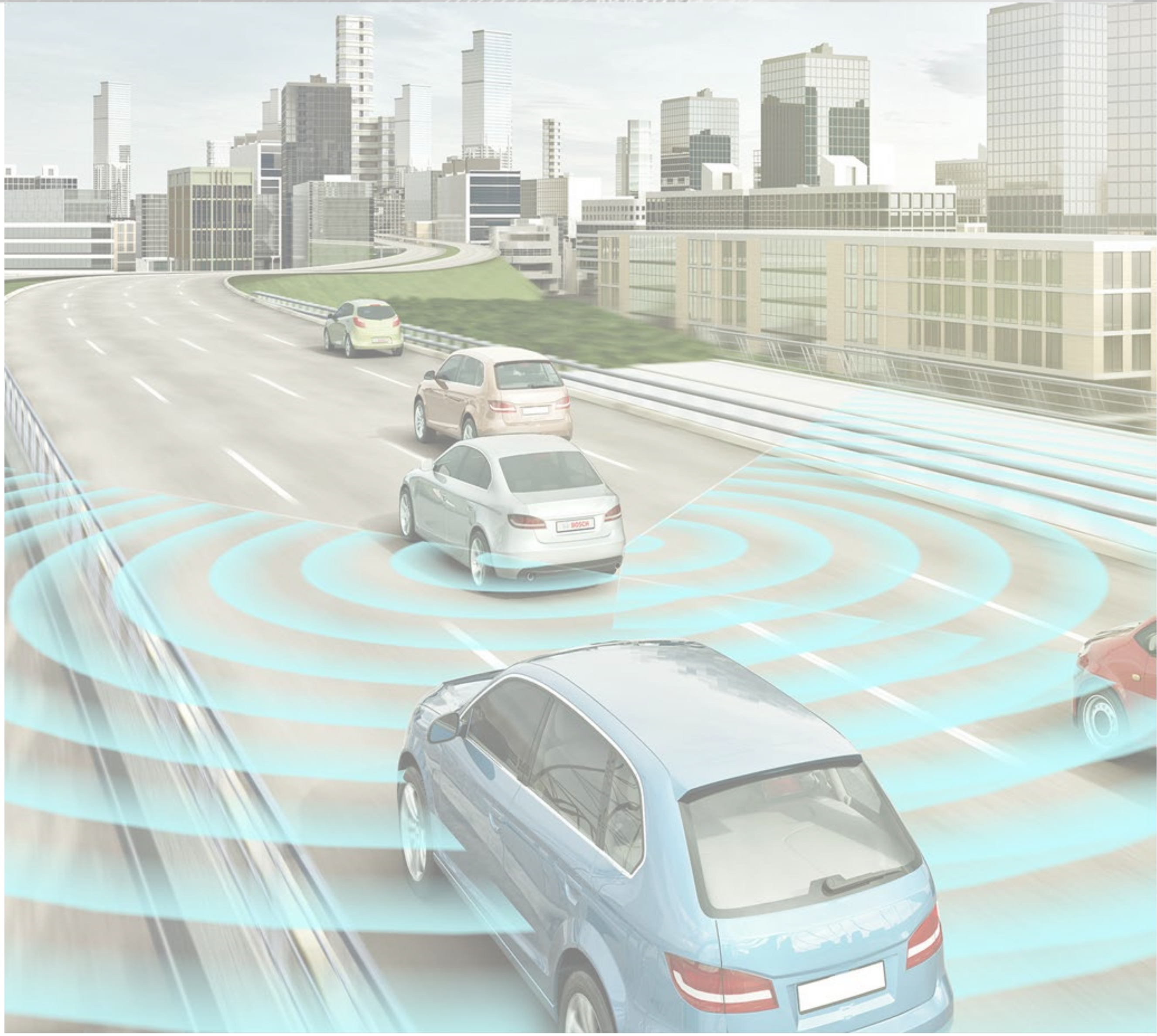
FUTURE VEHICLES: FUSION OF HETEROGENOUS SET OF SENSORS AND SYSTEMS



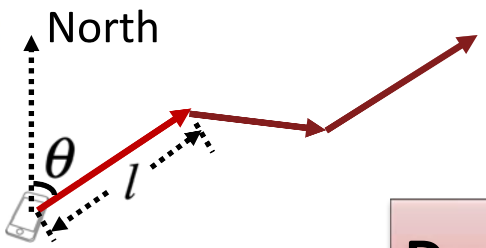
Sensors Functionalities in Autonomous Vehicles

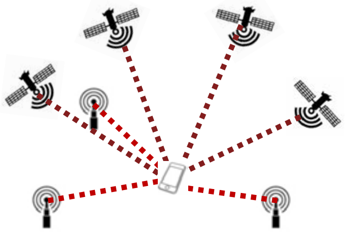
Sensors Functionalities in Autonomous Vehicles can be divided into two major categories:

- **Exteroceptive Sensors: for detection and identification**
  - LiDAR
  - Cameras
  - RADAR
  - Ultrasonic sensors
- **Proprioceptive Sensors: for localization**
  - GNSS
  - Wheel odometry
  - Accelerometer
  - Gyroscope
  - 5G



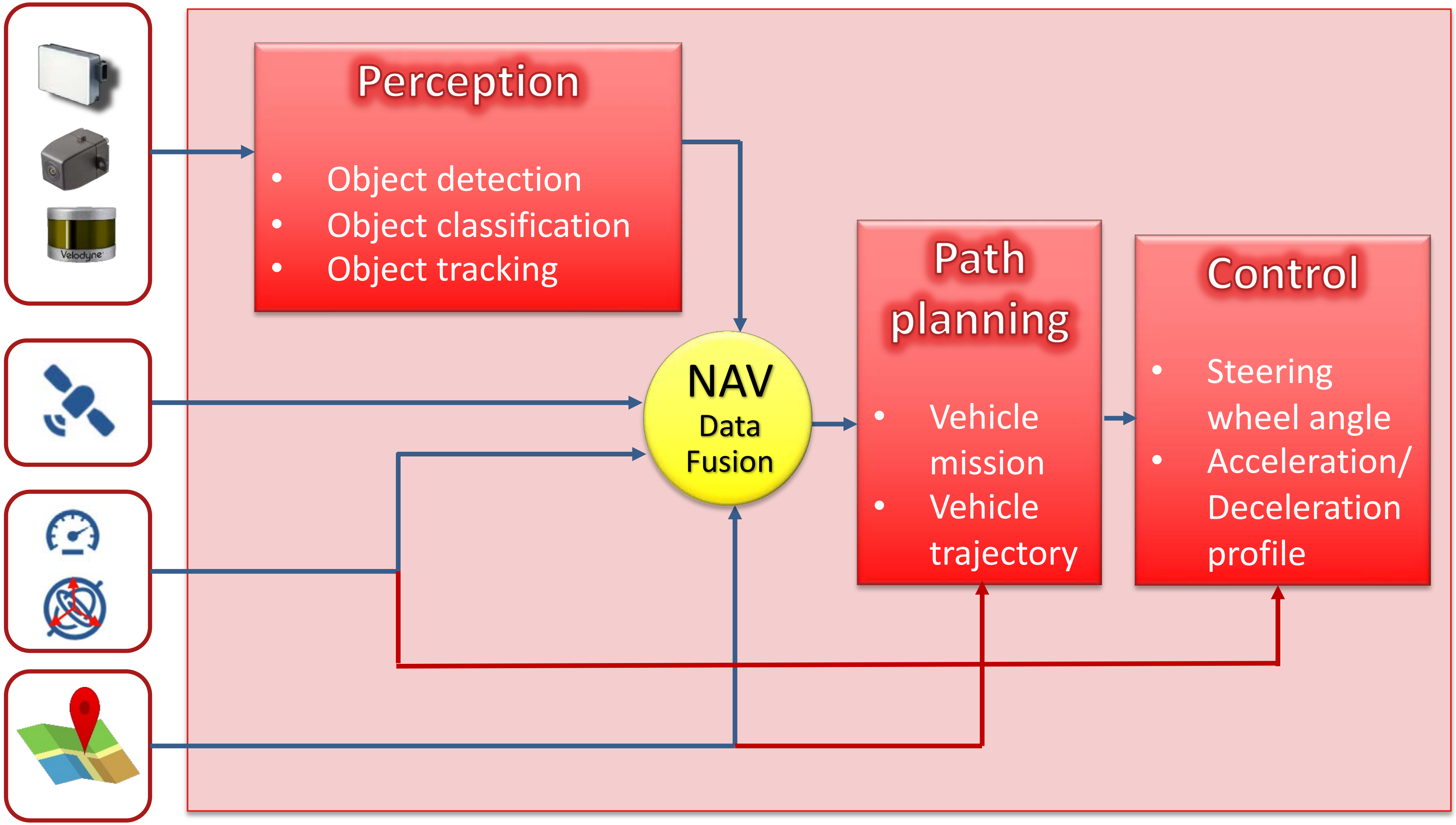
Classification of Navigation Technologies Concepts





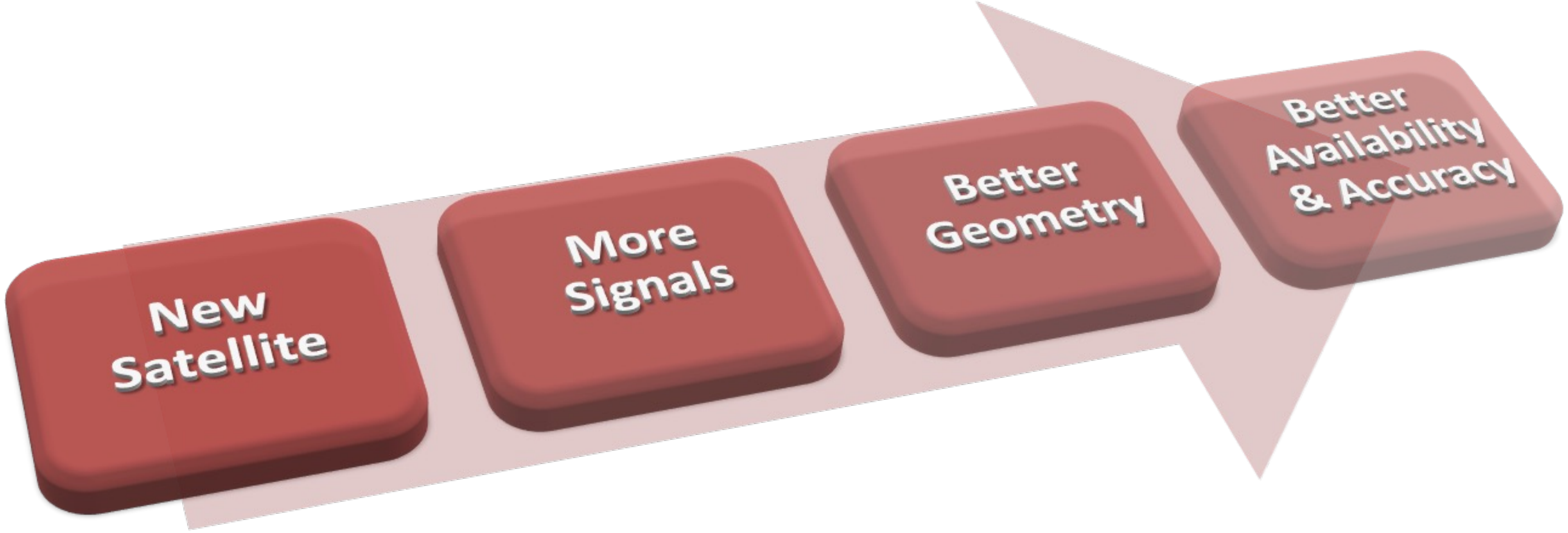
- **Navigation**
  - **Dead Reckoning**
    - Mechanization
      - Measurement integration
    - PDR
      - Step detection
      - Step length
      - Alignment
    - Odometry
      - Visual (VO)
      - Laser (LO)
      - Radar (RO)
  - **Position fix**
    - GNSS
    - Wi-Fi
    - NFC
    - RFID
    - Cellular towers

MAIN FUNCTIONALITIES OF SENSORS



- All the data gathered by these sensors is collated and interpreted together by the car's CPU or in-built software system to create a safe driving experience.

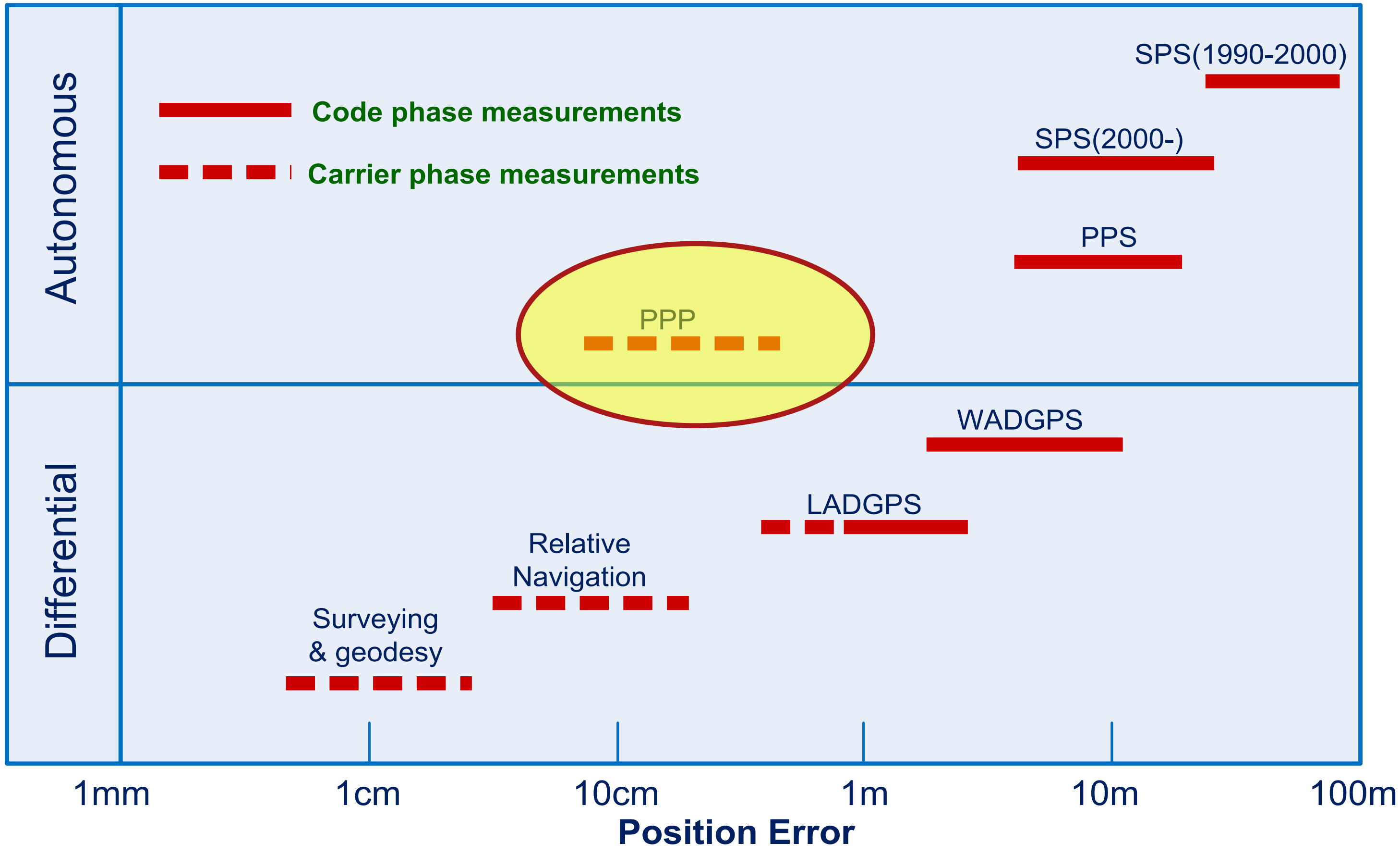
THE REVOLUTION IN GNSS SYSTEMS & SIGNALS



With the increased number of satellites and more sophisticated GNSS receivers, consumers will be able to operate in a wider range of conditions in the field.

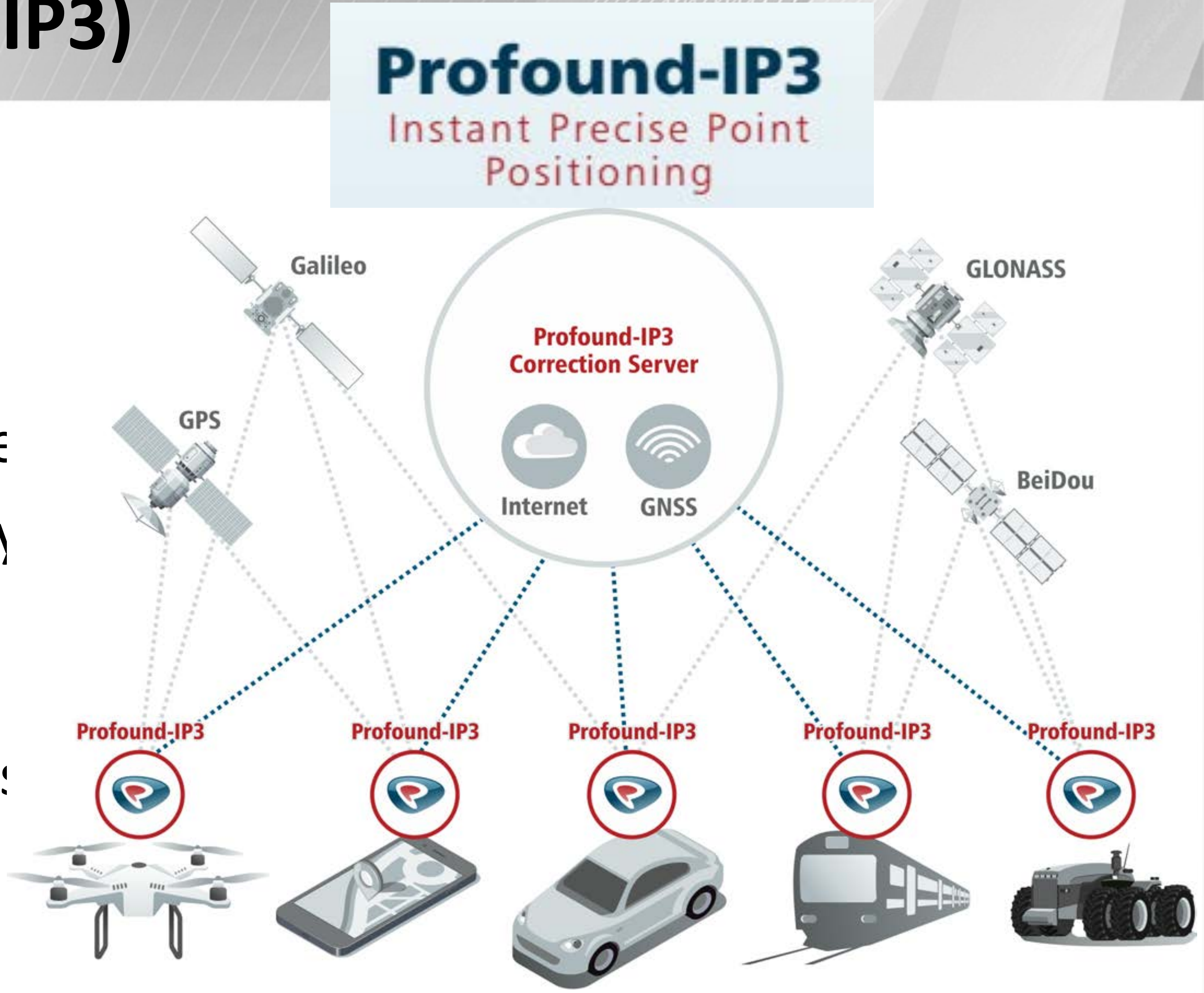
Accuracy and Cost: No Technology Can Compete with GNSS

Besides being globally available, GNSS meets two important pillars: **accuracy and cost** by providing the whole range of navigation accuracies at very low cost. It is also highly portable, has low power consumption, and is well suited for integration with other sensors, communication links, and databases.



PPI's Instant PPP (IP3)

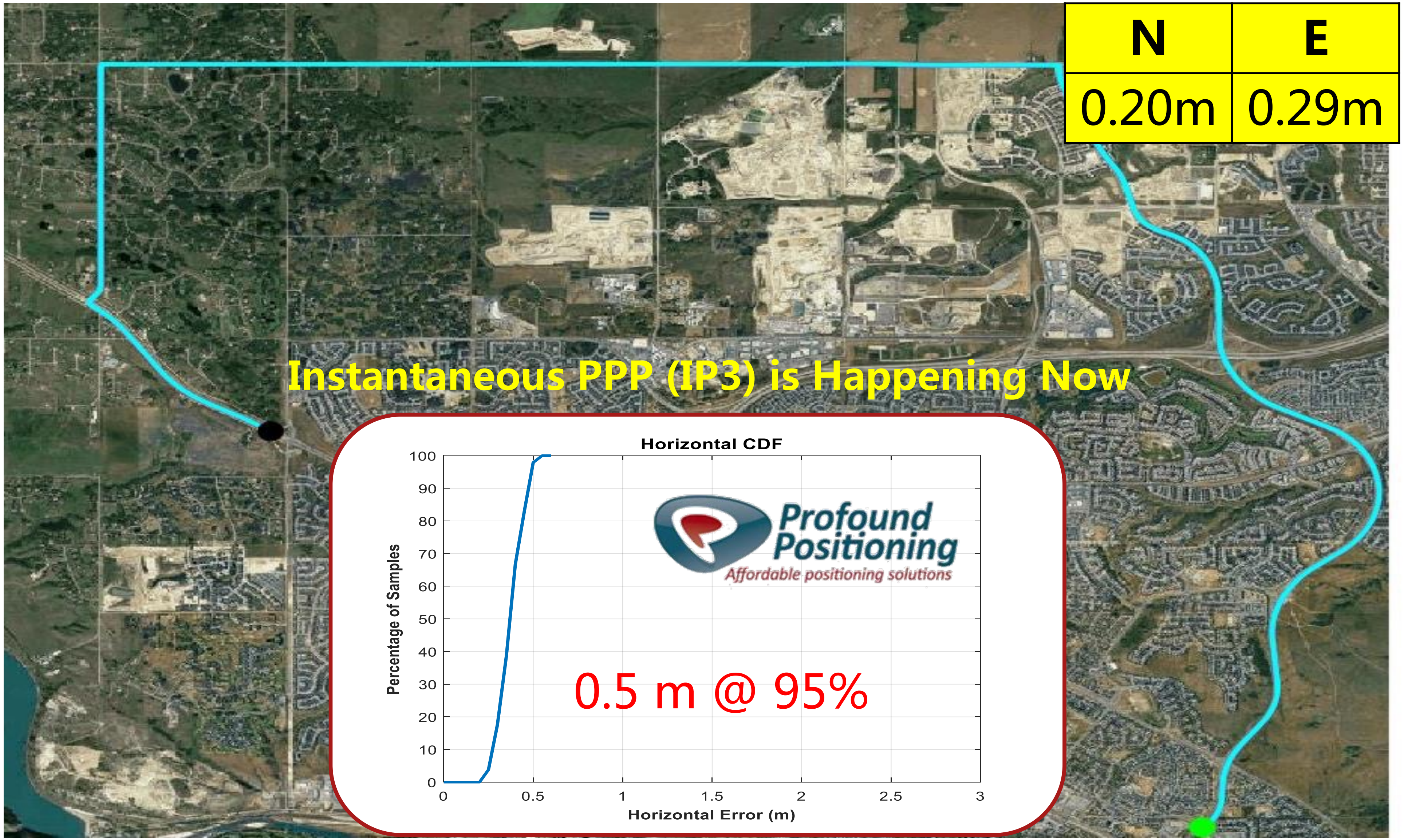
- ✓ IP3 is currently the only low-cost instant PPP engine in the market
- ✓ Low-cost GNSS for mass-marke
- ✓ Lane-level positioning accuracy - 50 cm CEP, single-frequency
- ✓ Globally available positioning without requiring base station
- ✓ Instant convergence
- ✓ Positioning engines for customer platforms



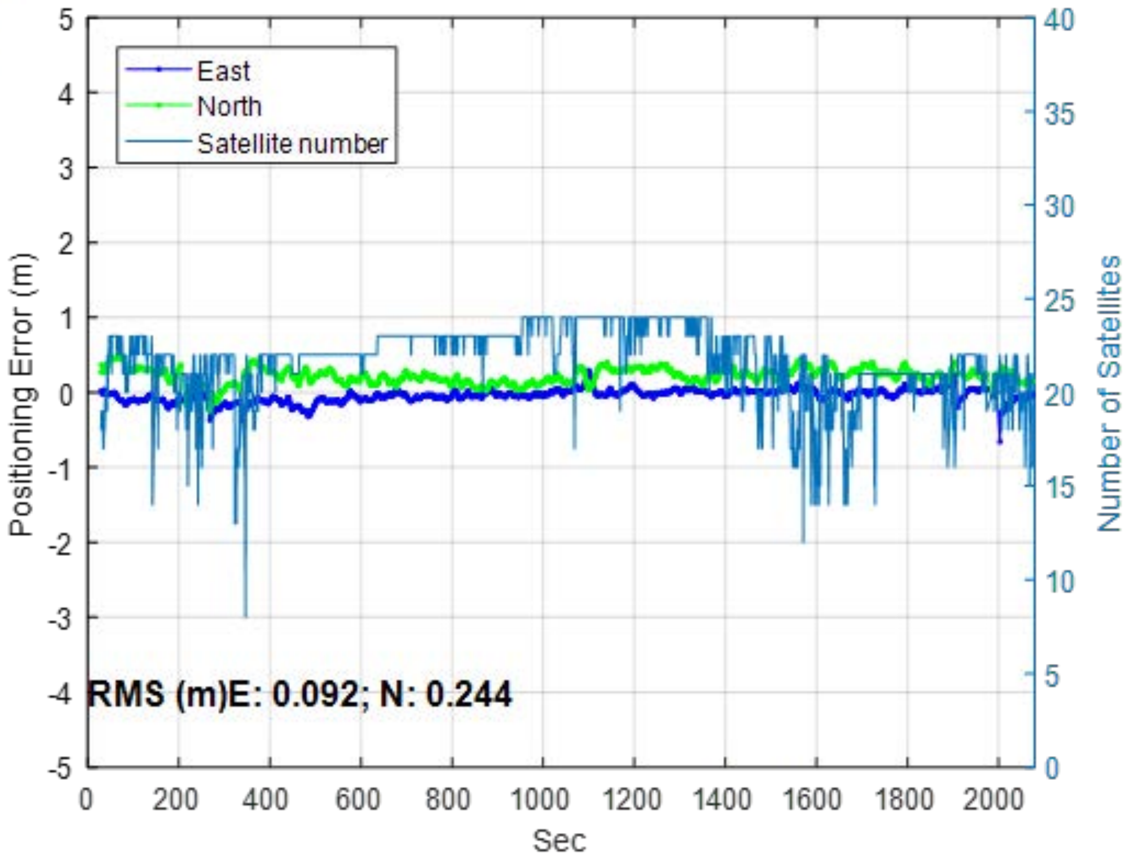
No more waiting around for a device to get a precise location.

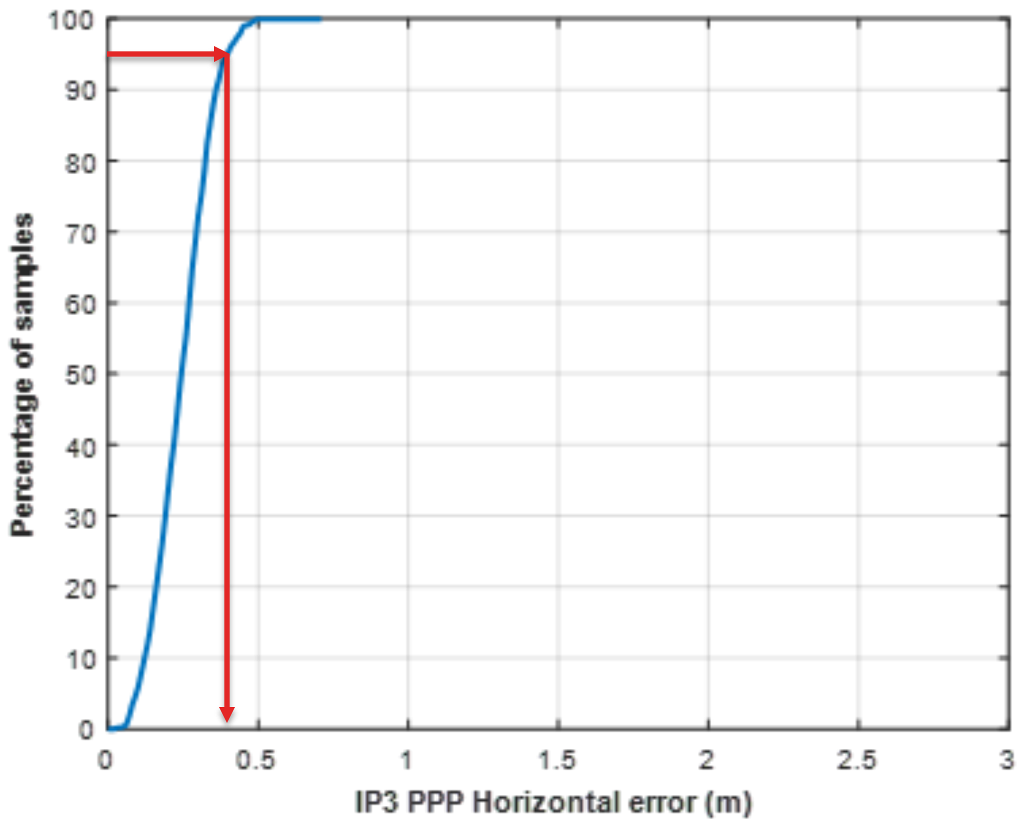
PROFOUND IP3 – A LANE-LEVEL NAVIGATION TECHNOLOGY WITH CONSUMER GNSS

N	E
0.20m	0.29m

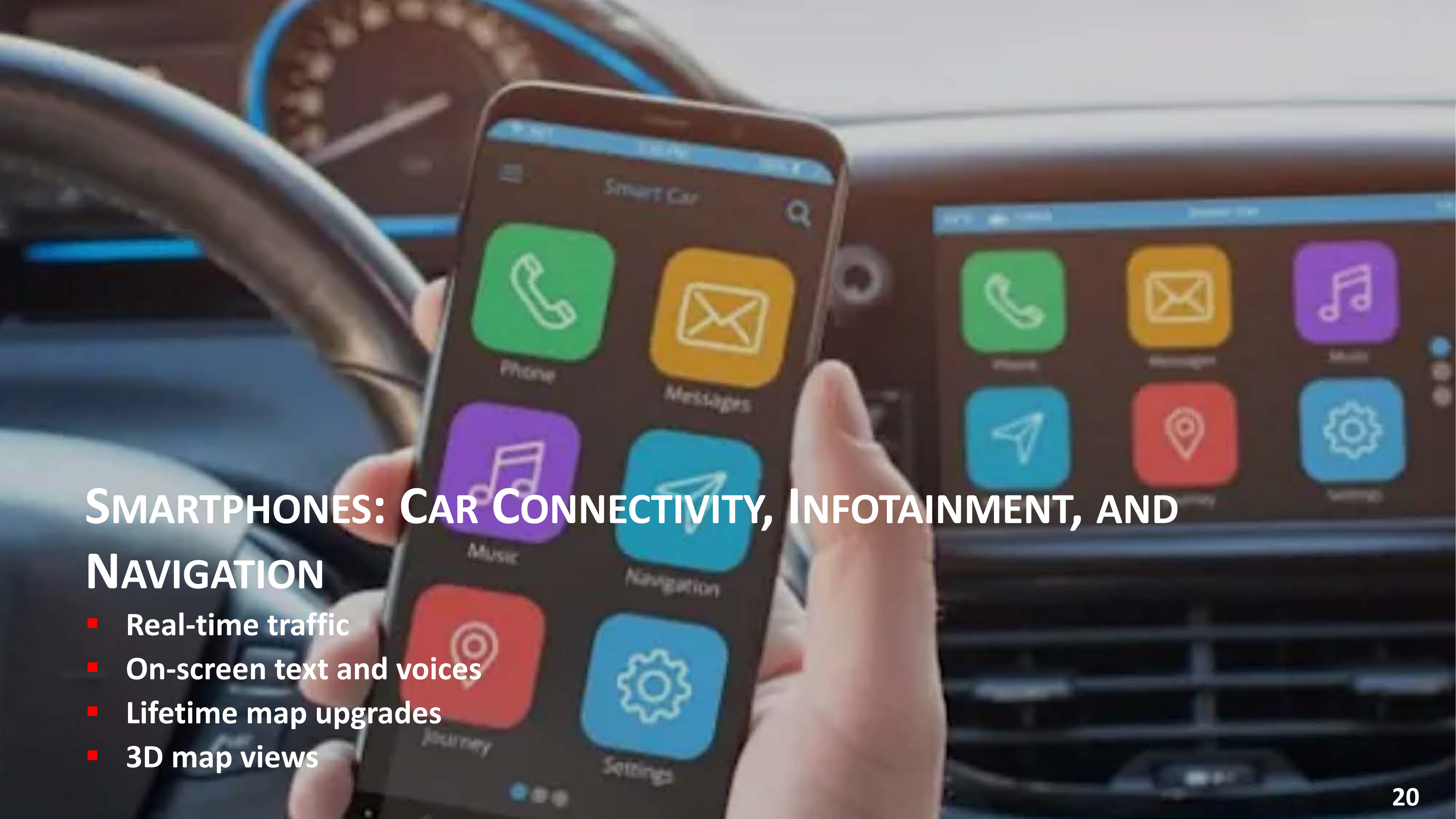


Performance in the field: sub-urban area





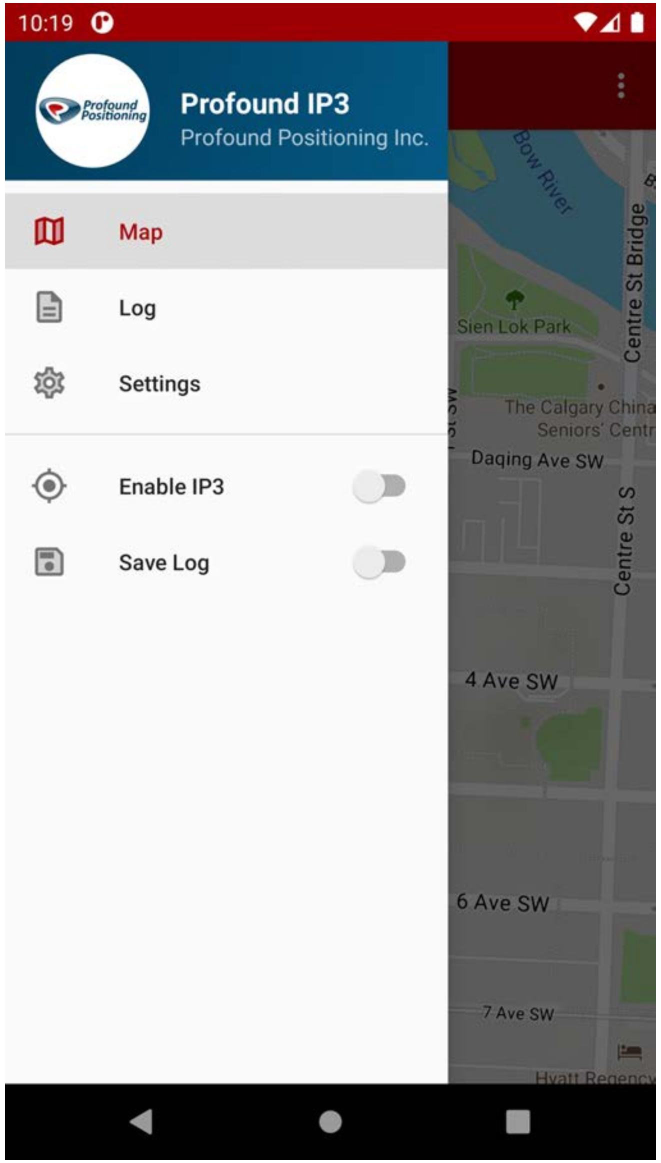
More than 95% of the IP3 position errors are within 0.5 m and the maximum horizontal error is less than 1 m.



Smartphones: Car Connectivity, Infotainment, and Navigation

- Real-time traffic
- On-screen text and voices
- Lifetime map upgrades
- 3D map views

PROFOUND-IP3 APP

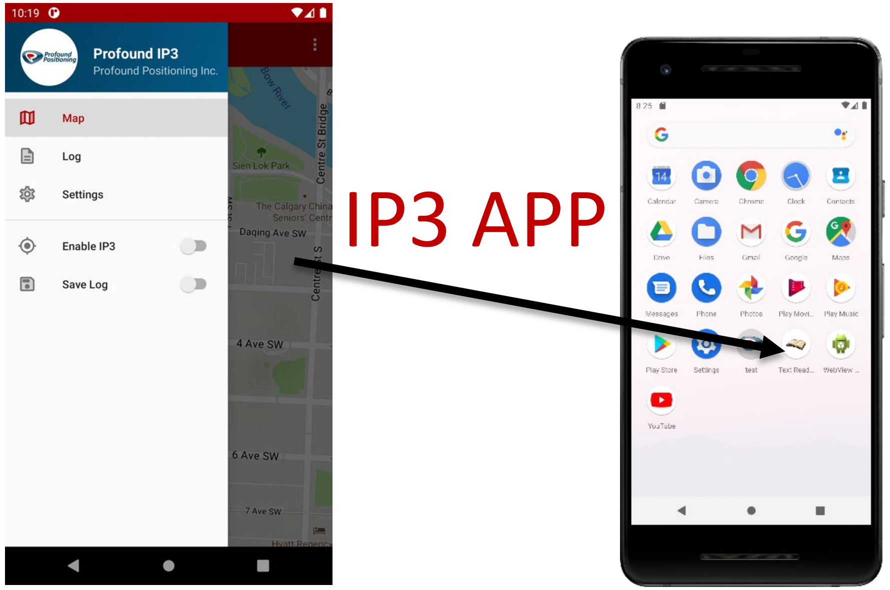


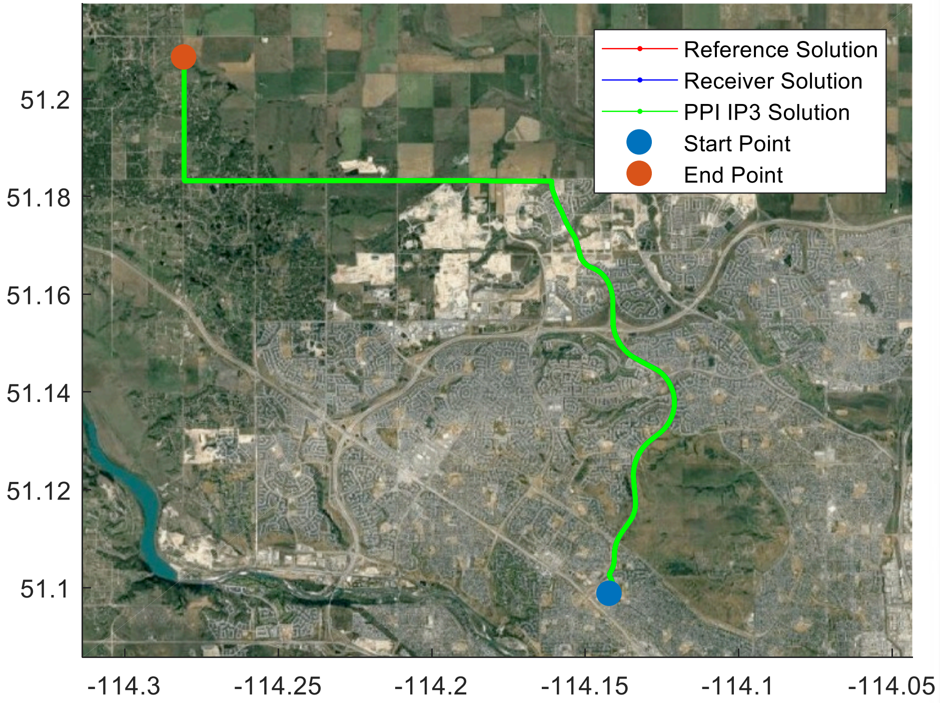
Cellphone brands	GNSS chipsets onboard	ADR & L1 & L5
Samsung S20 (2)	Broadcom 47755	Supported
Xiaomi MI8 (2)	Broadcom 47755	Supported
Huawei P40 (1)	Hisilicon	Supported

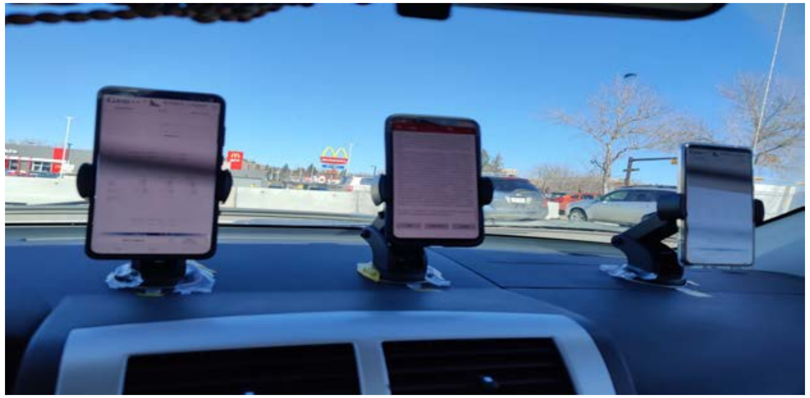
PROFOUND IP3-MOBILE KINEMATIC PERFORMANCE

This dataset has the following specs:

Environment	Kinematic – on dash
Phones	Samsung S20 (Black and White) and Xiaomi Mi 8 (Black)
Length:	around 45 minutes (first 20 min are static)
Test time	2:28 pm - 3:12 pm Calgary time
Corrections	CLK91
Library	Version 845

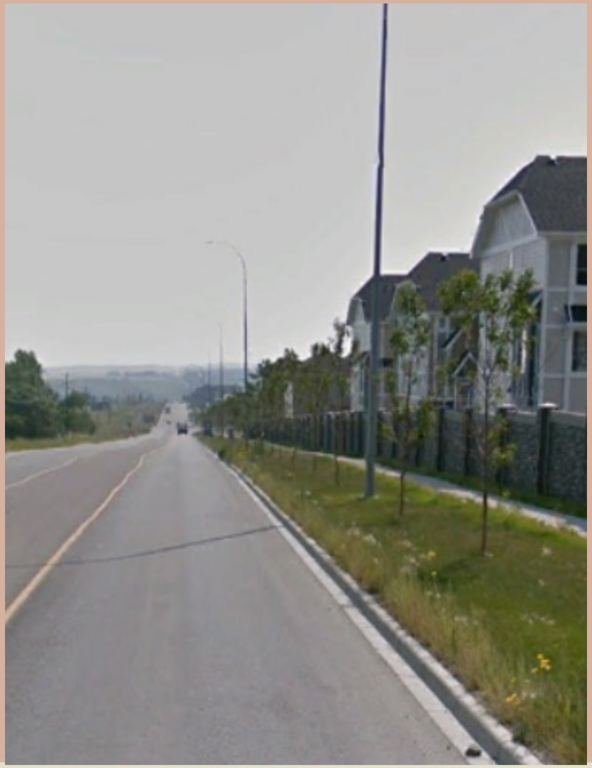






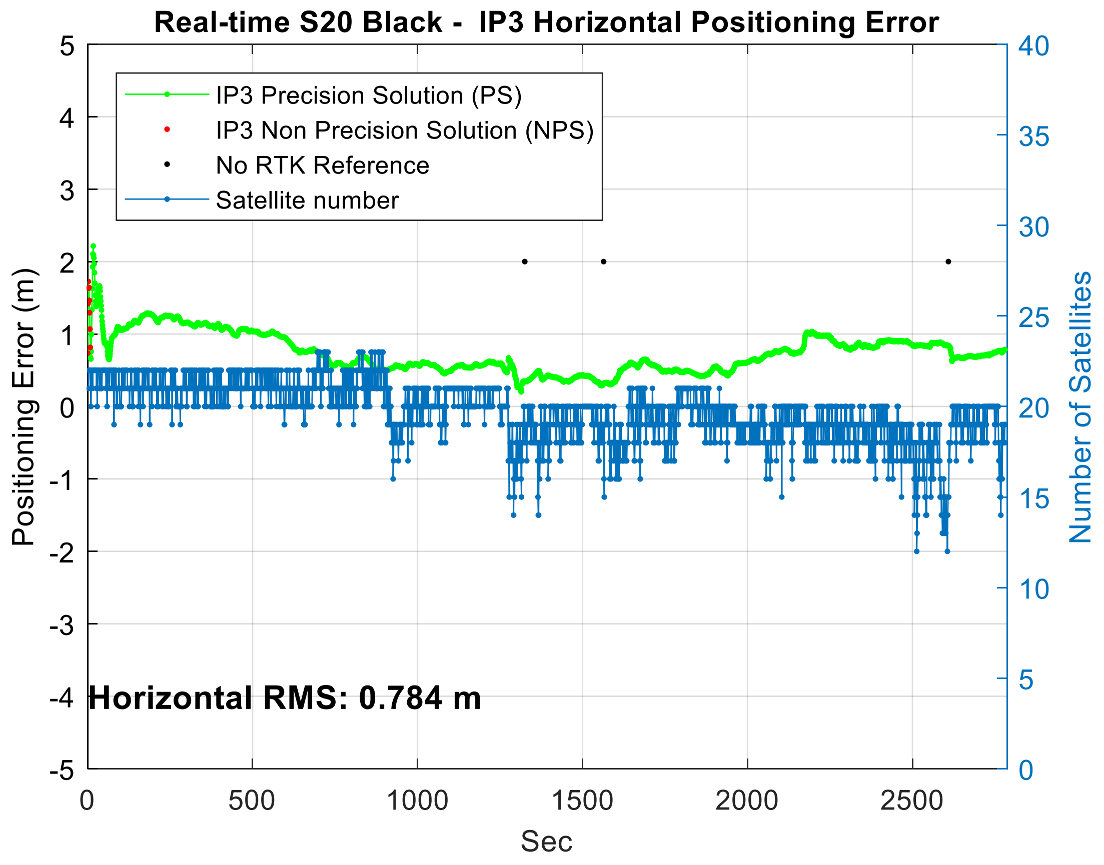
IP3 - On-dash Driving Test Environments

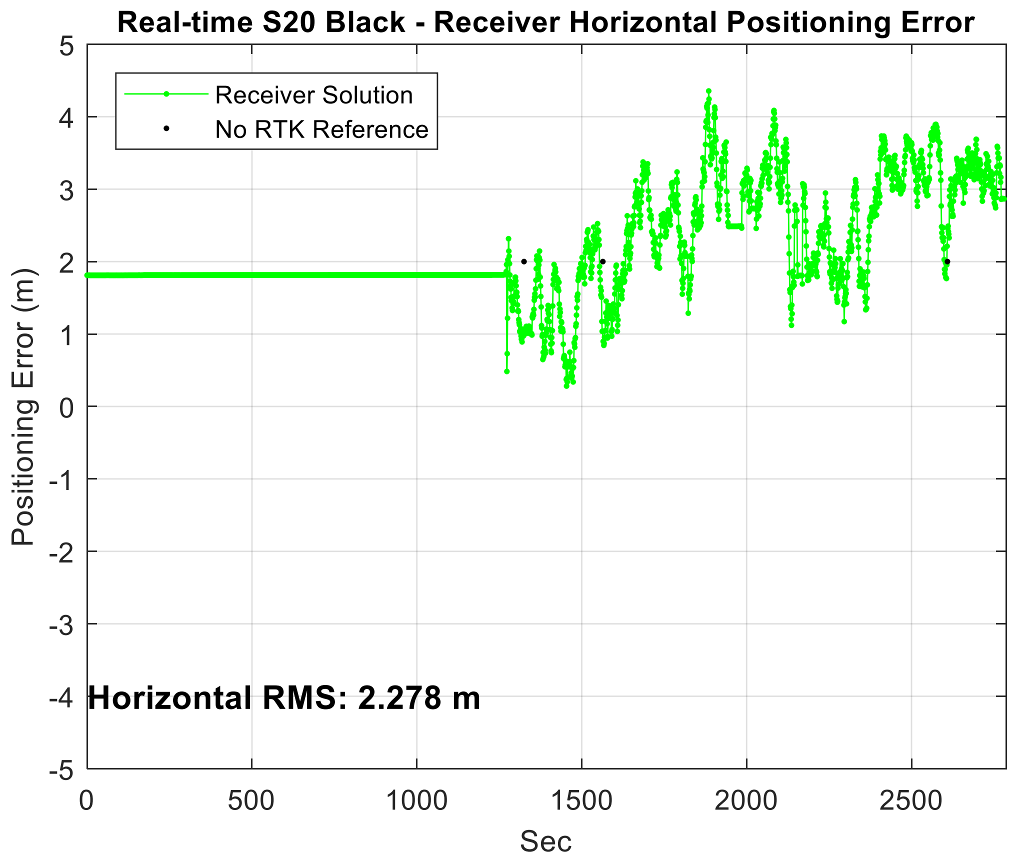
Residential Area	Open-sky Area	Highway with Overpasses	Road with Low Buildings



IP3-Mobile Results – Samsung S20

Real-time results on March 15, 2021

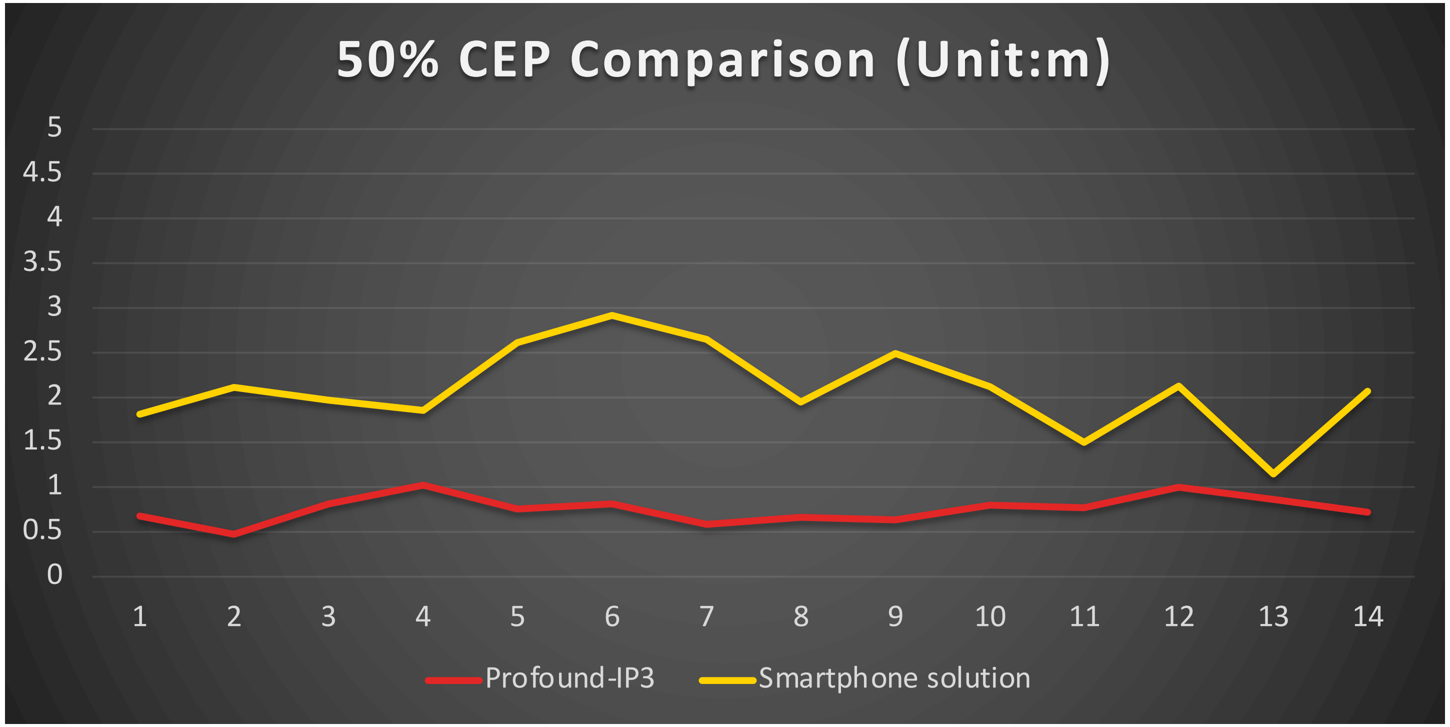




SUMMARY (50% CEP, SAMSUNG S20 ULTRA)

Test #	Profound-IP3 (GNSS-only)	Smartphone solution (GNSS+other sensors)
1	0.675m	1.814m
2	0.474m	2.114m
3	0.812m	1.972m
4	1.023m	1.858m
5	0.759m	2.616m
6	0.815m	2.919m
7	0.588m	2.654m
8	0.66m	1.947m
9	0.635m	2.496m
10	0.800m	2.125m
11	0.772m	1.500m
12	1.001m	2.128m
13	0.861m	1.147m
14	0.724m	2.071m

50% CEP of Profound-IP3 and Samsung S20 Ultra smartphone solution



Average: Smartphone solution (GNSS + other aiding) 1.845m

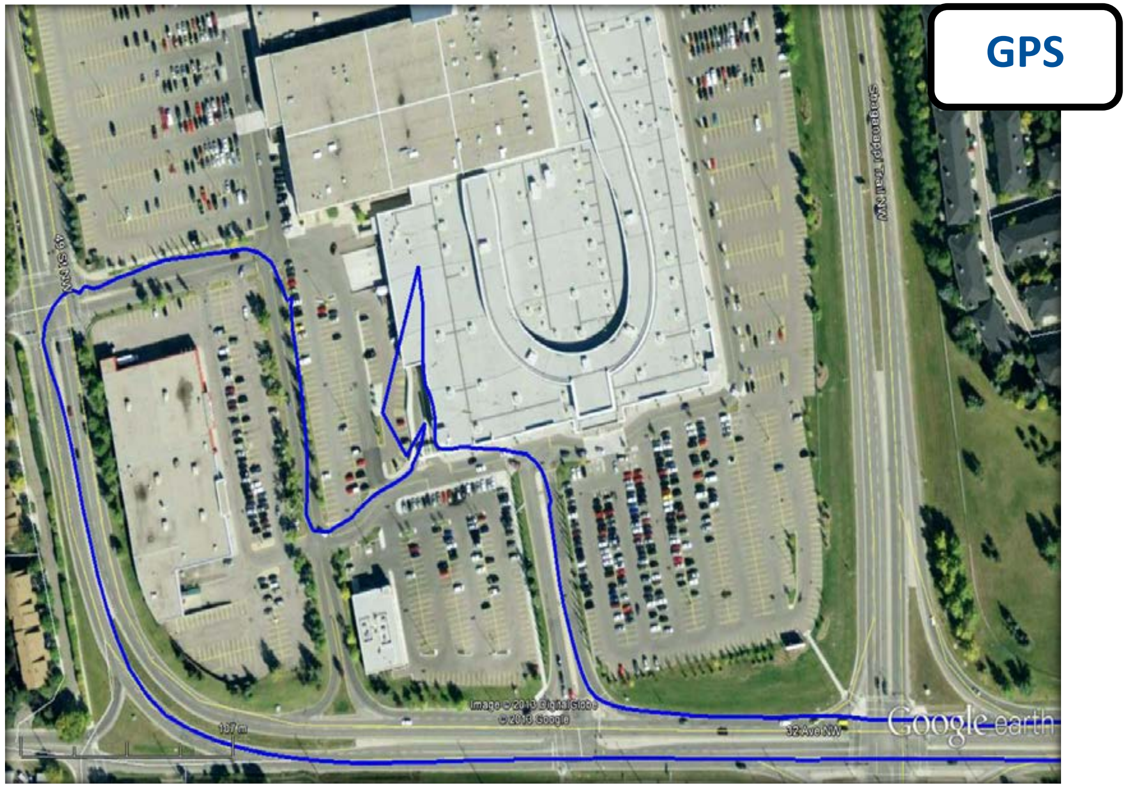
Profound-IP3 (GNSS-only) 0.757m

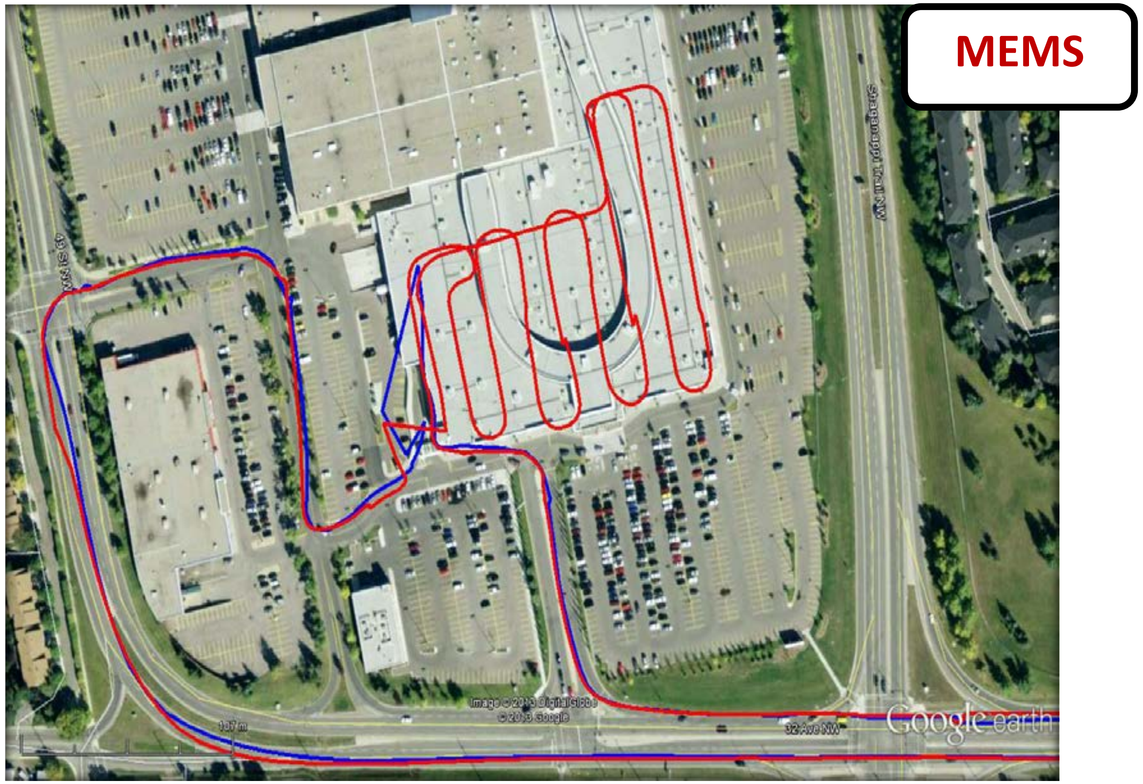
THE POTENTIAL OF SMARTPHONES

- Smartphones will deliver more than just communication: combines information from **“absolute” wireless** signals with **“relative” sensors** signals to provide continuous & accurate navigation

TURN BY TURN - UNDERGROUND MALL

- The Samsung Galaxy phone wirelessly connected to the vehicle via Bluetooth to obtain vehicle speed.
- Wireless connection, all processing done on the mobile device





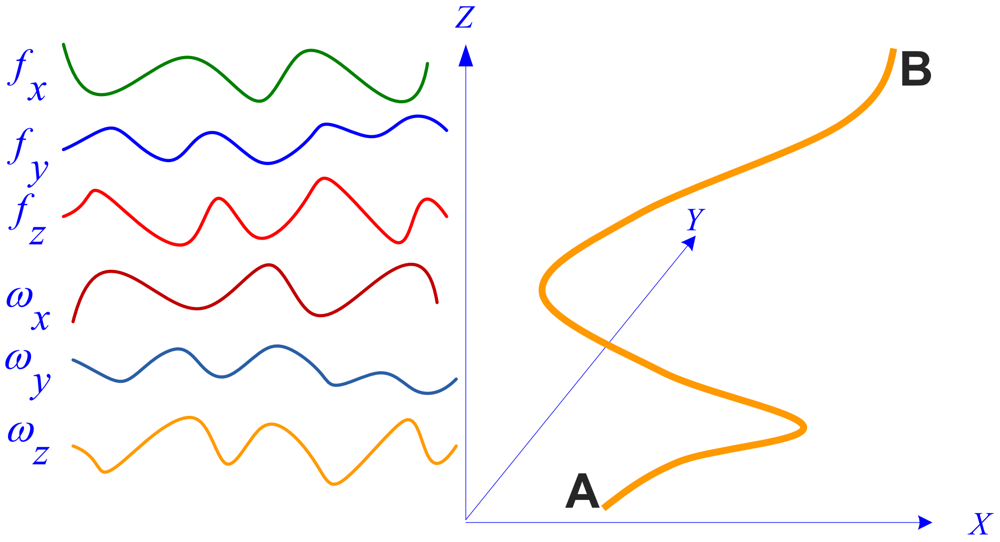
CONTINUITY – A MAJOR NAVIGATION PROBLEM

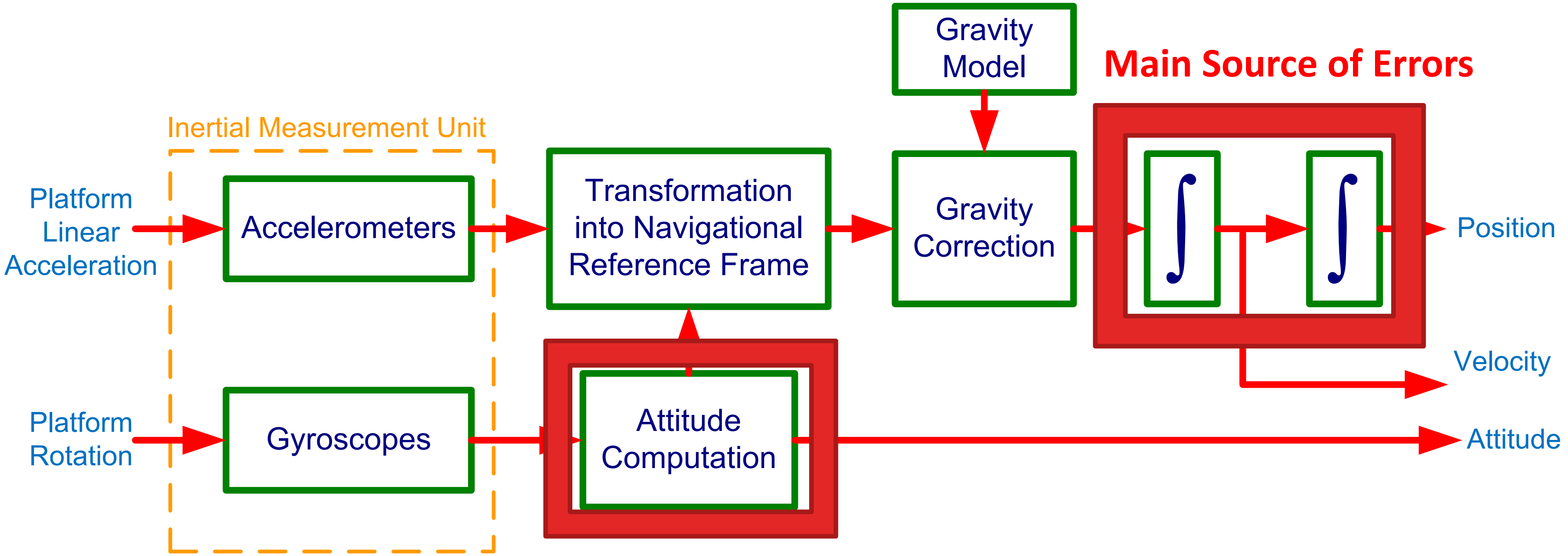
Technology	Covered Parking And Tunnels	Downtown Multipath areas	Foggy conditions	Rain Conditions	Snow and slippery Roads	Range and Resolution
GNSS	❌	?	✅	✅	✅	N/A
Vision	✅	✅	❌	❌	?	✅
Lidar	✅	✅	✅	?	?	✅
Odometer	✅	✅	✅	✅	?	N/A
Radar	✅	✅	✅	✅	✅	❌
IMU	✅	✅	✅	✅	✅	N/A

✅ Work ❌ Does not Work ? Limited Operation

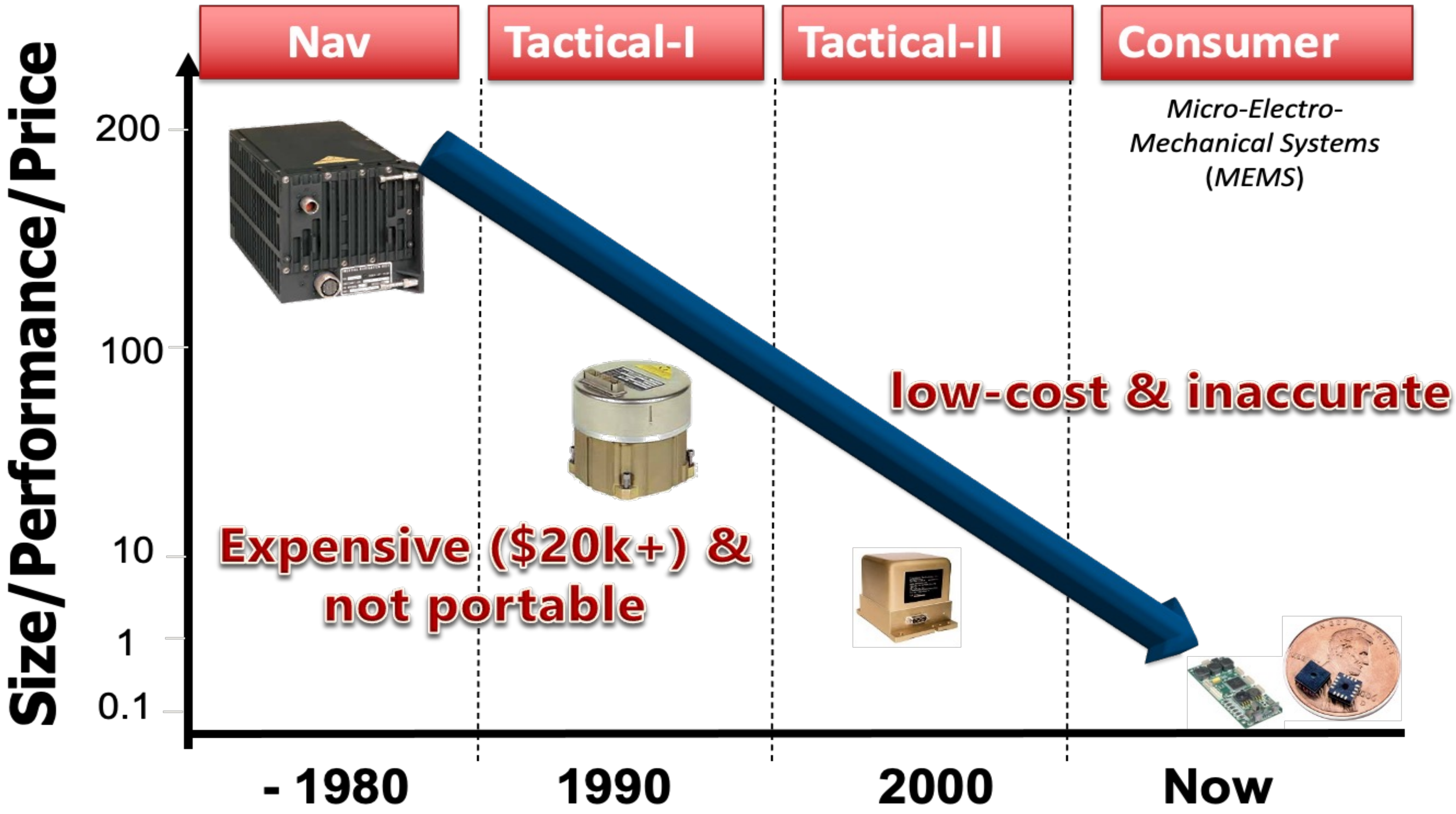
✅ Inertial and Radar Sensors are the only navigation technologies that can work everywhere and under any weather and operational conditions

INERTIAL TECHNOLOGY – AN ALWAYS ON NAVIGATION





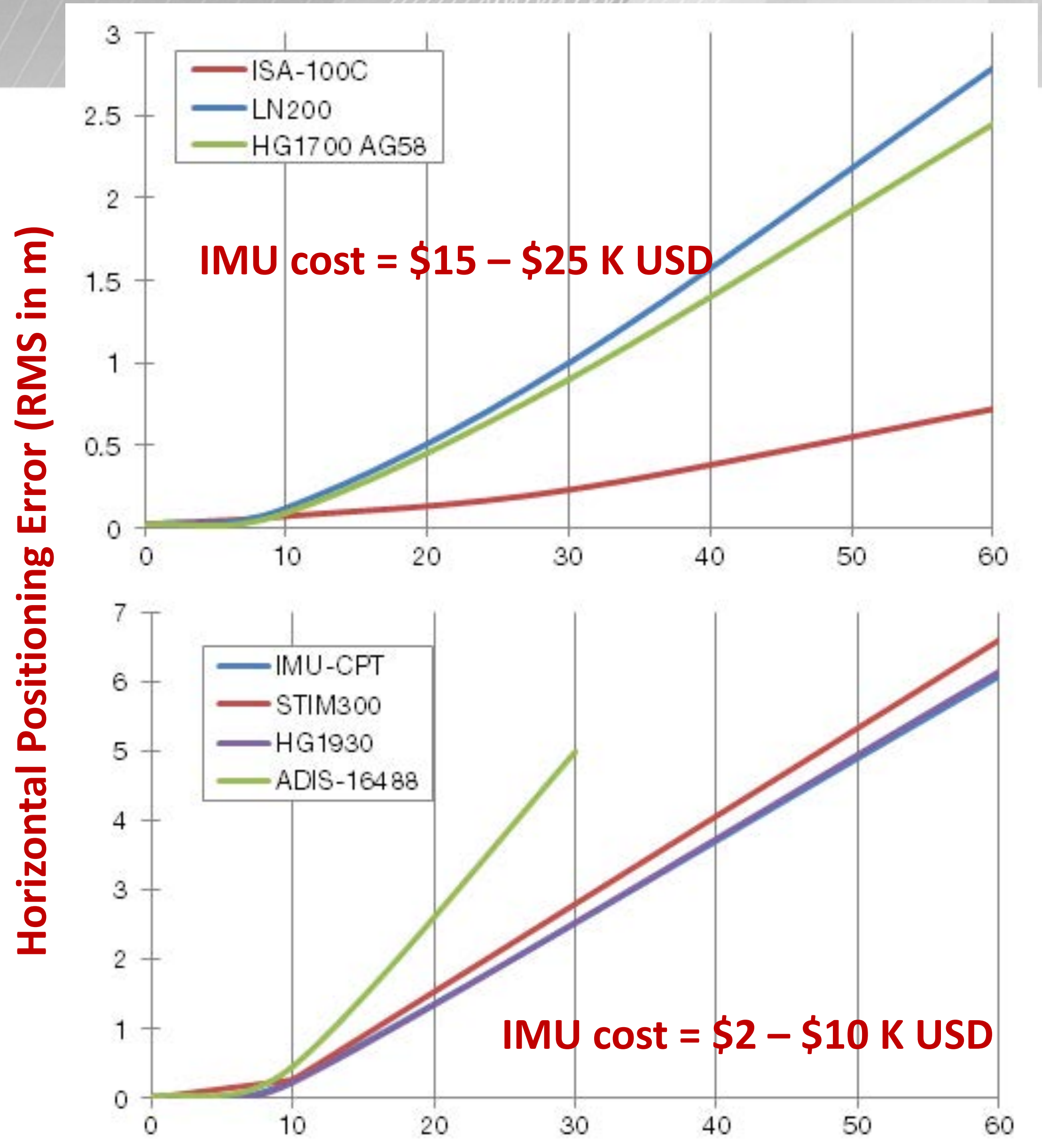
INS Technology Roadmap – Price is No Longer an Issue



Current Systems are Expensive and Not Accurate

Performance of Different Commercial IMUs during 1-minute without GNSS

Performance Grade	Bias Stability
Consumer	30-1000°/hr
Industrial	1-30°/hr
Tactical	0.1-30°/hr
High-end Tactical	0.1-1°/hr
Navigation	0.01-0.1°/hr
Strategic	0.0001-0.01°/hr



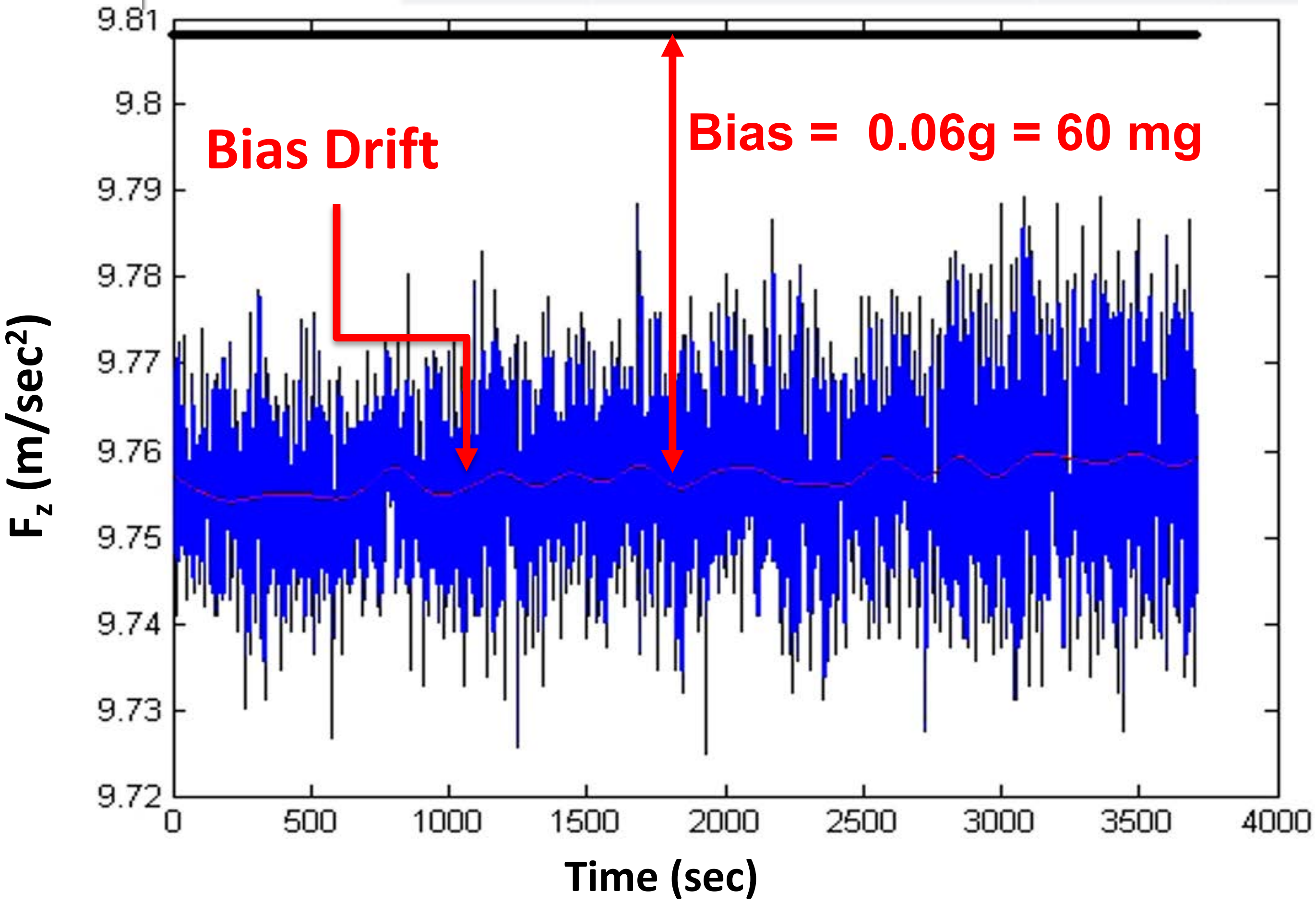
WHY INERTIAL DRIFT WITH TIME

Low cost and Automotive sensors exhibit:

- Large biases
- Large noises
- Large drift
- Different characteristics between on/off
- Propagation of errors due to the integration process

MPU-6500 (6-axis)

Sensor	Error	Range
Gyro	Initial Biases at 25 ºC	± 5 deg/s
	Variation over -40 to 85 ºC	±0.24 deg/s/ºC
Accel.	Initial Biases	± 60 mg
	Variation over 0 to 70 ºC	± 0.64 mg/ºC



A static MEMS-based Accelerometer (costing <5$) along the vertical direction **(should measure 1 g)**

EXAMPLE OF THE PERFORMANCE OF CURRENT SYSTEMS - MODULE PRICE: USD 25

u-blox UDR/DR module with 3D sensors

Receiver type	72-channel u-blox M8 engine GPS/QZSS L1 C/A, GLONASS L10F, BeiDou B1I, Galileo E1B/C SBAS L1 C/A: WAAS, EGNOS, MSAS, GAGAN
Nav. update rate	Up to 20 Hz
Position accuracy	2.0 m CEP
UDR position error	Typically <10% of distance covered without GNSS (up to 60 s)
DR position error	Typically 2-3% of distance covered without GNSS

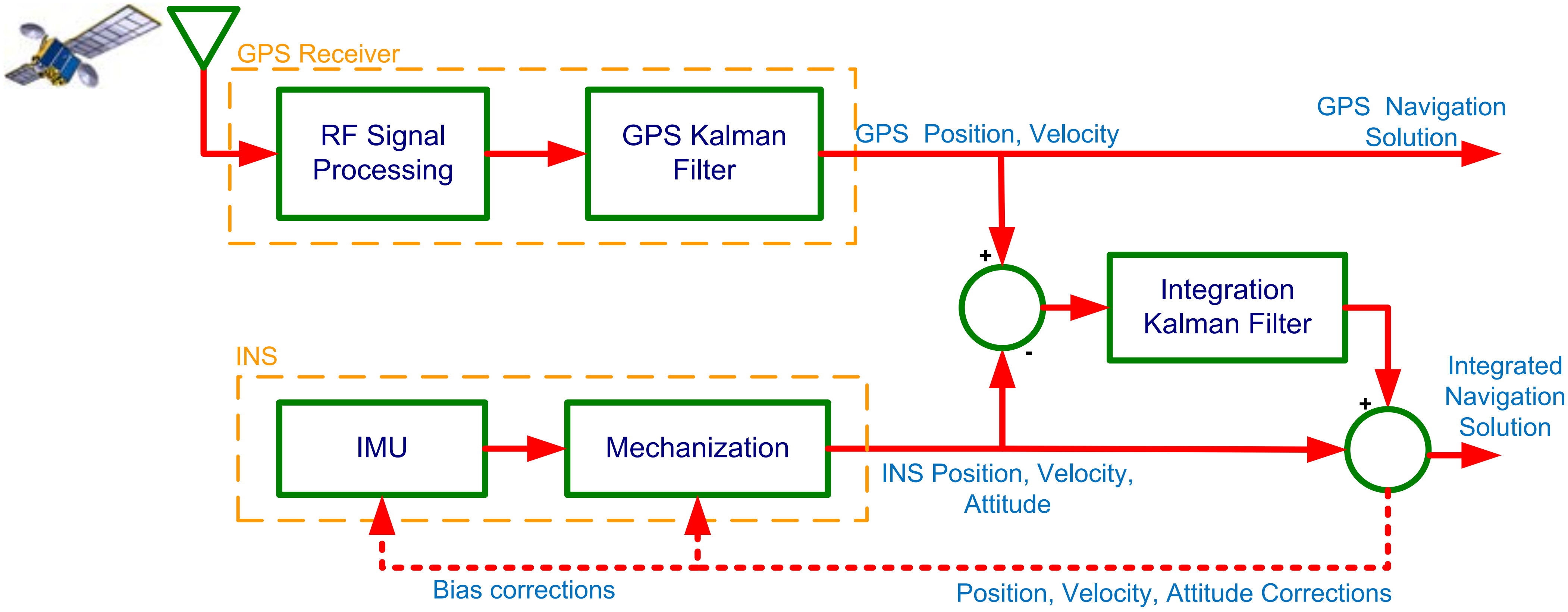
Methods of Improving the Accuracy of INS

Methods for improving the performance of the INS can generally be classified as:

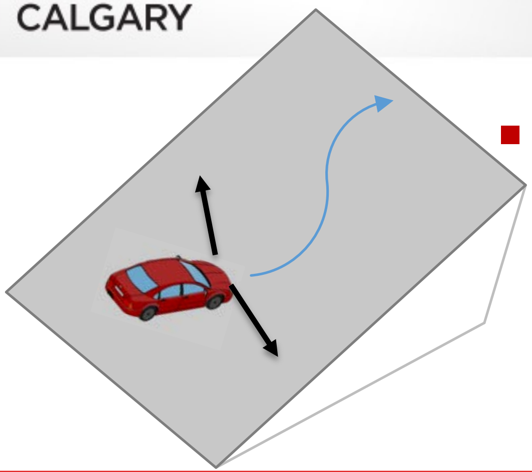
Integration	Motion Constraints	Calibration - Modeling	New INS Designs
With other navigation sensors (e.g. GNSS) imaging or Nav Aid	Using information about the motion of the platform	For eliminating and modeling of sensors errors	New sensors design that minimize sensor errors

IMPROVING INS PERFORMANCE BY INTEGRATION

- Loosely Coupled Integration Scheme - GPS solution is performed first using a GPS Kalman filter then the filtered position and velocity are sent as input to the INS Kalman filter.



IMPROVING INS PERFORMANCE BY MOTION CONSTRAINTS



- Useful aiding information can be derived from the fact that vehicles:
  - Move on a surface;
  - Can stop occasionally
  - Height does not change much in highways

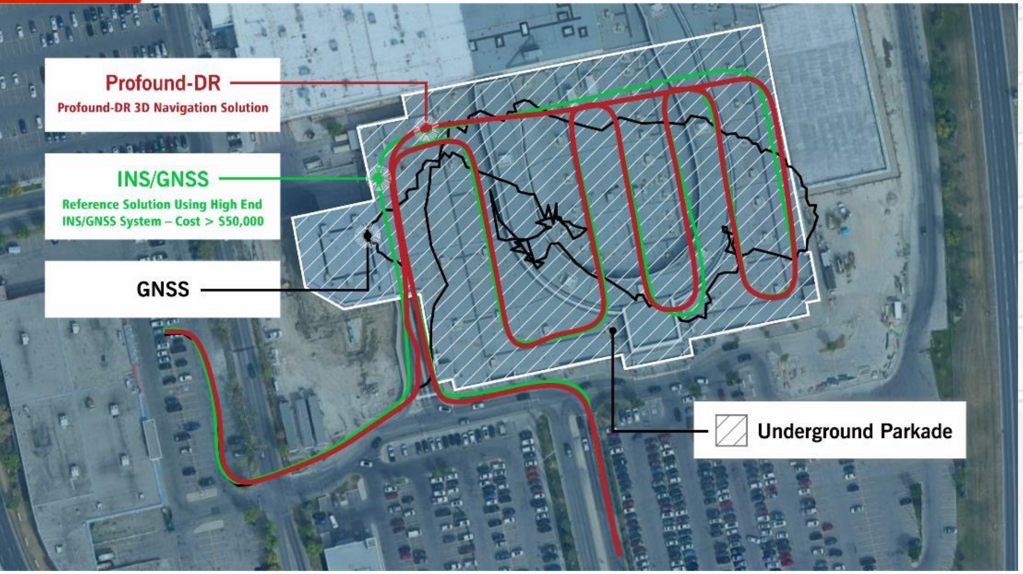
Motion Constraints	Characteristics
Zero-velocity updates (ZUPT)	Static mode; Velocity pseudo-measurement;
Non-holonomic constraints (NHC)	Moving mode; Velocity pseudo-measurement; Affected by sideslip;
Zero integrated heading rate (ZIHR)	Static mode; Angular pseudo-measurement;
Height constraint	Moving or static mode; Act as the 4th satellite observation

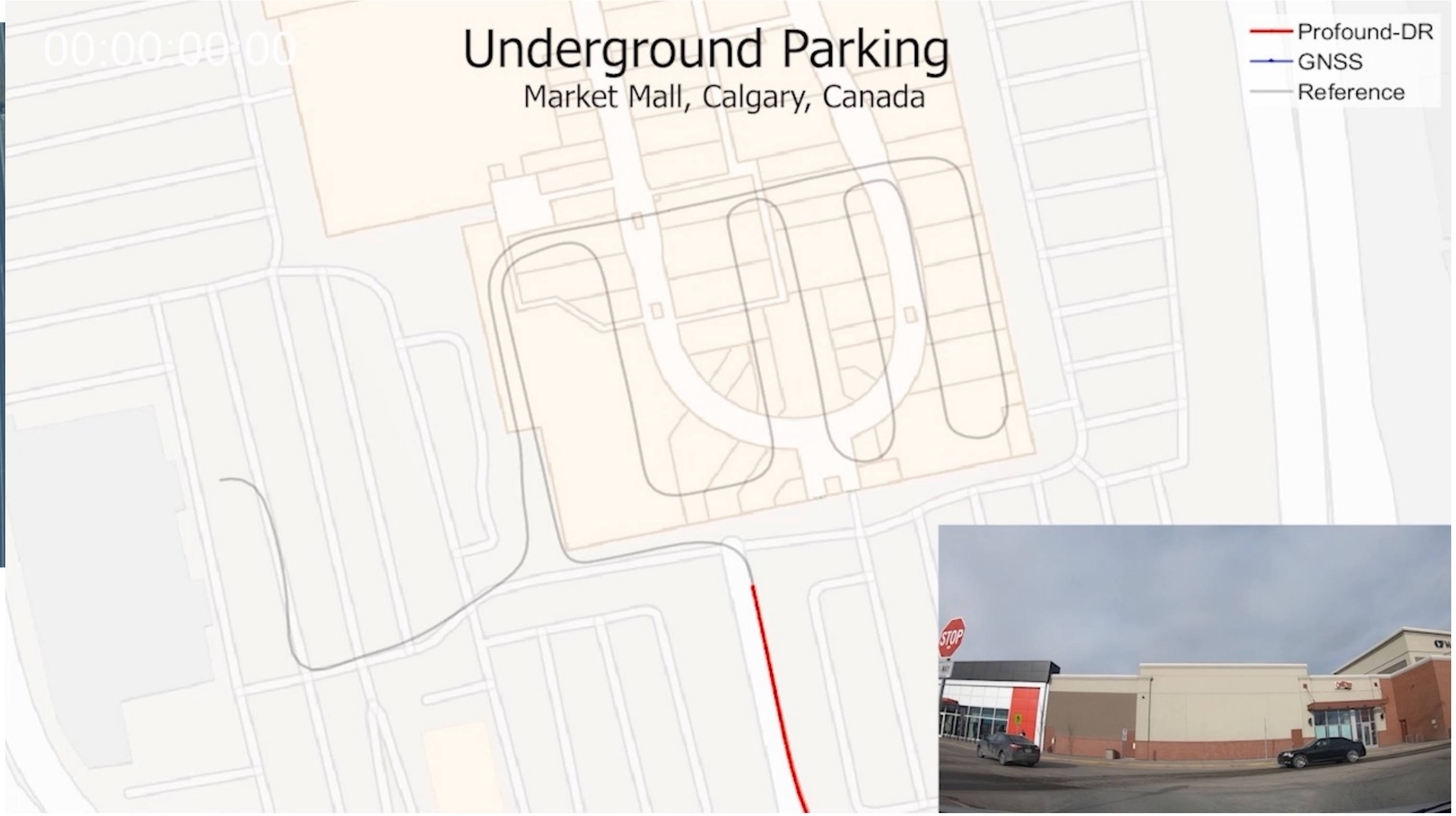
SENSORS EXAMPLE

GNSS receiver	Low-cost u-blox EVK-M8T
IMU	Low-cost TDK InvenSense (6-axis MEMS IMU)
Vehicle Speed	On-board OBD-II circuit to connect the vehicle OBD-II module to log speed data
Reference	• Post-processed TC DGNSS/INS solution • GNSS and INS measurements from NovAtel SPAN unit • Post-processing using NovAtel Waypoint Inertial Explorer
Processor	• Cortex-M4F based STM32F4 Micro-controller

Profound Positioning
Affordable positioning solutions

VALET PARKING OF SELF DRIVING CARS USING STAND-ALONE <$5 MEMS IMU + OBDII

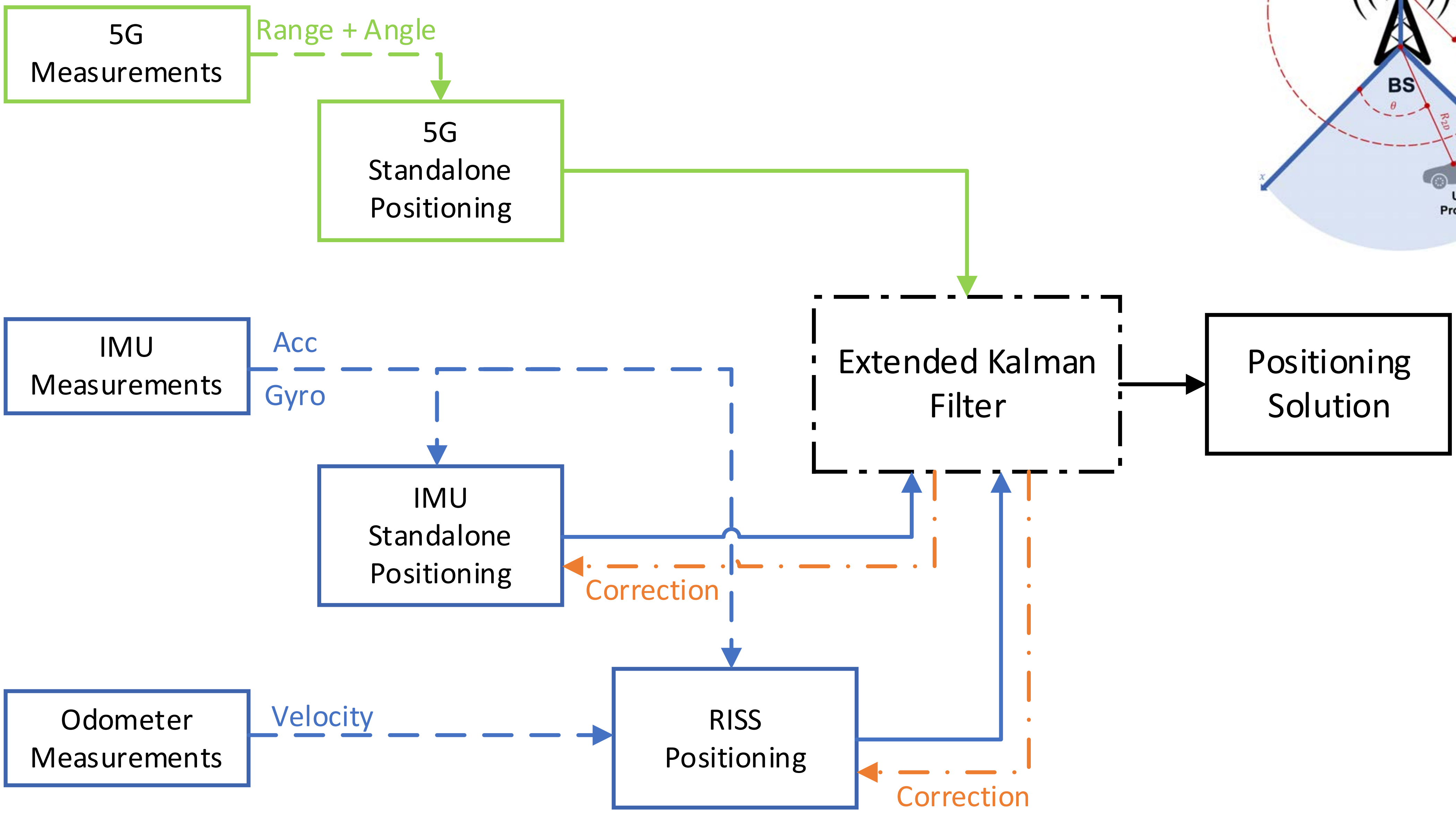


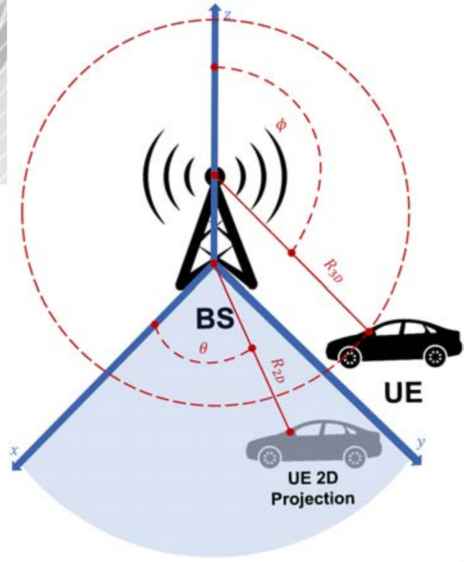


Profound-DR positioning accuracy with errors less than 1% of the travelled distance for several minutes of GNSS signal loss with integrated dollar-level inertial sensor measurements with speed measurements from vehicles speedometer.

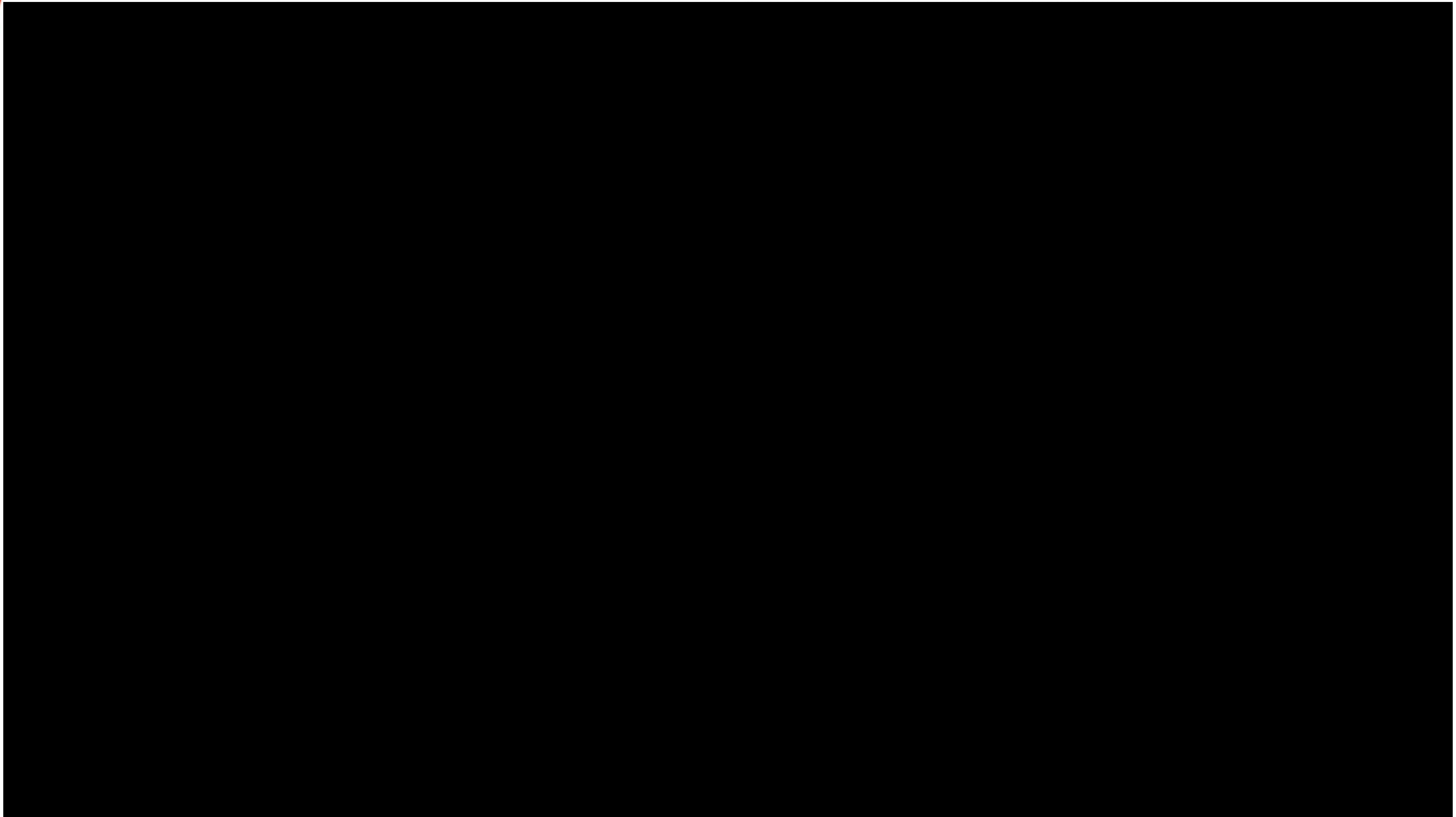
Ref Solution System cost: $50,000
PPI DR Solution System Cost <$10

General Structure of Integrating 5G





The Potential of 5G



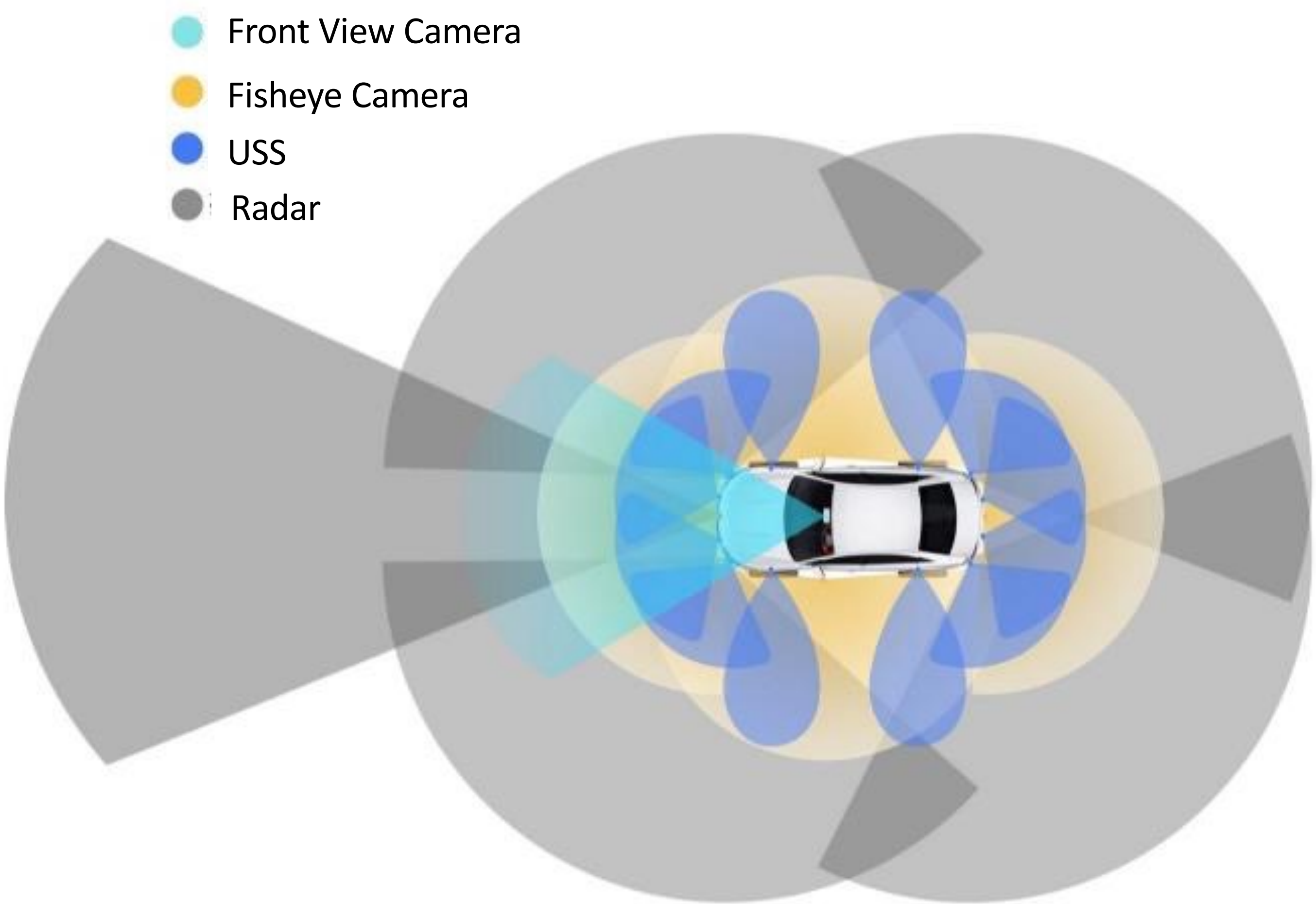
VISUAL ODOMETRY

VISION AIDING CONTINUOUS NAVIGATION

- Real time detection of static/dynamic objects from images.
- Estimate navigation states based on optical flow of the images.
- Fuse the GPS/INS navigation using the navigation solution derived from images.

SENSOR FUSION - A KEY COMPONENT OF FUTURE AUTONOMOUS VEHICLES

- 4x Fisheye Camera
- 1x Front View Camera
- 5x Radar
- 12x USS
- Steering Wheel Angle
- 4 Wheel Rotation Pulse
- GNSS
- IMU



Fisheye Camera Radar USS

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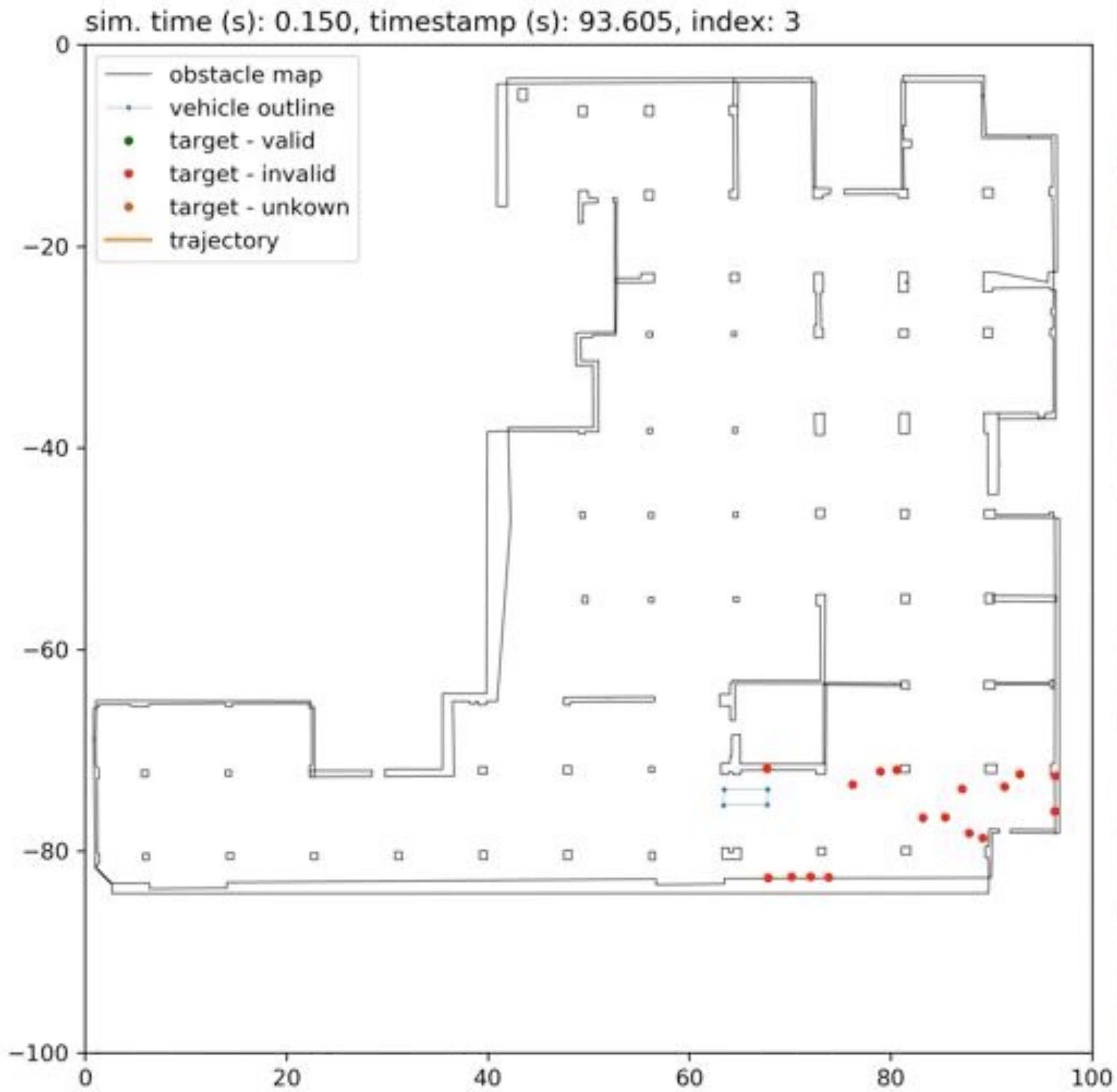
PRECISE POSITIONING FOR AVP IN DEGRADED VISION ENVIRONMENT

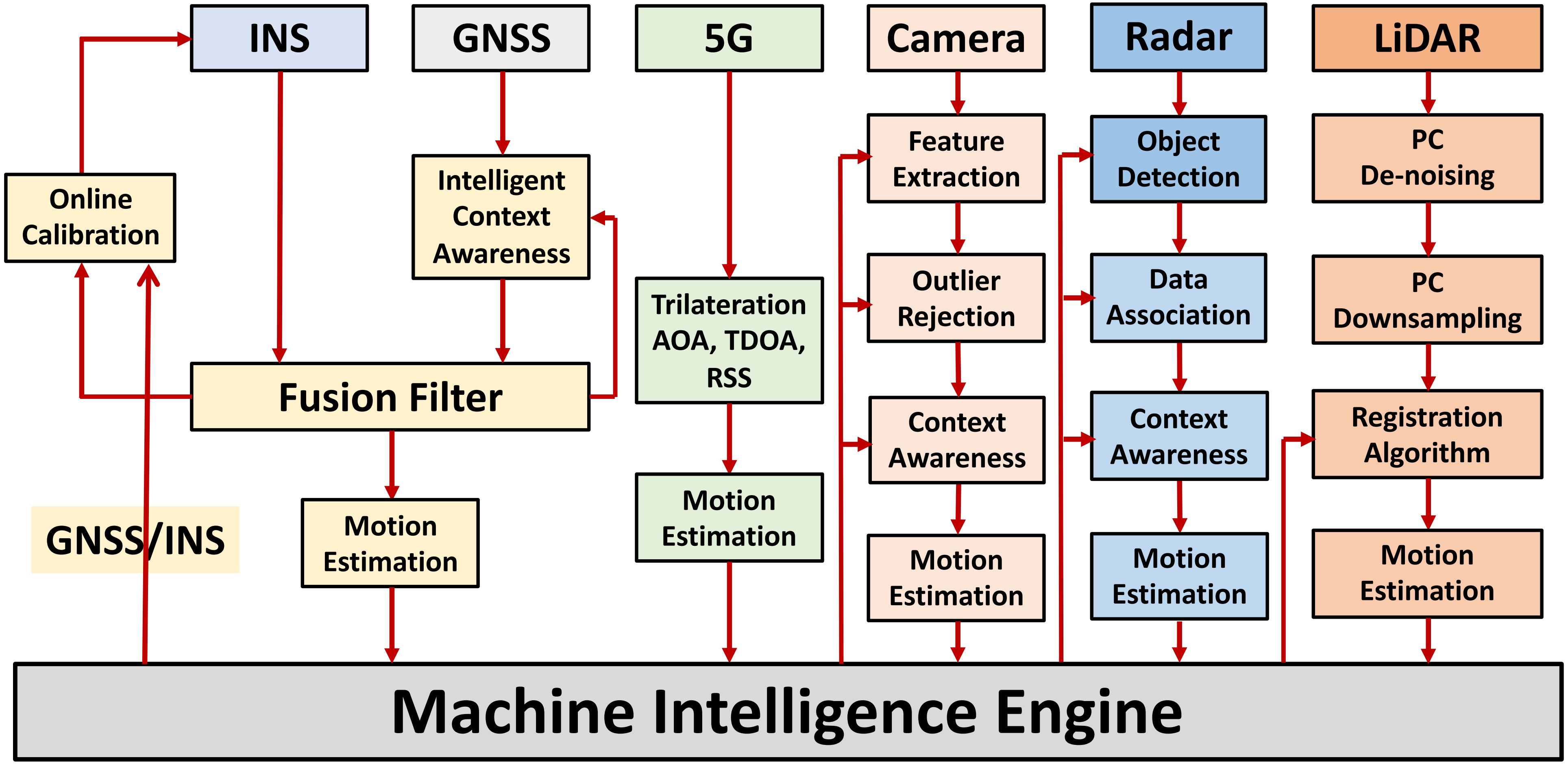
- MEMS-based IMU chip module integrated with Short Range Radar.
- SRR: Range=60m; FoV H/V: 150°/30° Number of points=64; 20Hz



Profound Positioning
Affordable positioning solutions

Intelligent Multi-Sensor System Precise Positioning

- Centralized Machine Intelligence based Processing and Multi-Sensor Deep Integration



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ACKNOWLEDGMENT

- **Funding Sources**

Canada Research Chairs

Natural Sciences and Engineering Research Council of Canada

- **My Research Group**

- **Credit:**
  - **Profound Positioning Inc.**

    Profound Positioning – Affordable positioning solutions
  - **Micro Engineering Technology Inc**

    METI – Micro Engineering Tech Inc.

SUMMARY

- **Navigation technologies are essential component of future AV because of :**
  - The need for navigation technologies that works everywhere
  - Market demands for low cost for the huge Location Based Services and IOT industries

- **Low-cost Sensors– Future Trends:**
  - Data fusion with the goal of minimizing the total error budget.
  - Calibration of the Sensors on-the-fly to minimize user intervention
  - Extended error models for long operation without GNSS

If self-driving cars can be driven safer and much more efficiently, it could save valuable lives and preserve the environment.