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SAFETY-CRITICAL POSITIONING
FOR AUTOMOTIVE APPLICATIONS: LESSONS FROM CIVIL AVIATION

Thursday, Nov 3, 2016

WELCOME TO
Safety-Critical Positioning for Automotive Applications: Lessons from Civil Aviation

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Co-Moderator: Lori Dearman, Sr. Webinar Producer

Who's In the Audience?

A diverse audience of over 600 professionals registered from 42 countries, and provinces representing the following industries:

- 17% GNSS Equipment Manufacturer
- 14% Automaker/Automotive Tech Supplier
- 12% System Integrator
- 11% Product/Application Designer
- 7% Regulatory/Public Agency
- 7% Civil Aviation
- 32% Other

Welcome from *Inside GNSS*

Richard Fischer
Publisher
Inside GNSS and Inside Unmanned Systems

Safety-Critical Positioning for Automotive Applications: Lessons from Civil Aviation

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Poll #1

When do you think fully autonomous cars will be mass produced? (Please select one)

- ***Before 2020***
- ***2020- 2025***
- ***After 2025***

Evolution of Automotive Safety Technology

Path to Connected & Automated Vehicles

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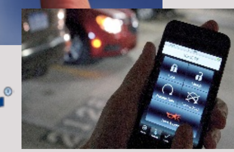
Automotive Safety Systems (1/2)

- Traditional safety features
  - Anti-Lock Braking Systems (ABS)
  - Airbags
  - Seatbelt pretensioning
  - Traction Control & Electronic Stability Control Systems
- Advance safety features (Function Specific Automation – Level 1)*
  - Adaptive Cruise Control (ACC)
  - Forward Collision Warning (FCW)
  - Lane keeping & Lane Departure Warning (LDW)
  - Brake Assist & Automatic Emergency Braking
  - Pedestrian detection
  - Backup Assist & Rear Cross Traffic Alert
- Next generation safety features (Combined Functions – Level 2)*
  - Tesla Auto Pilot
  - GM Super Cruise
- Autonomous driving (Limited to Full Self Driving - Level 3 & 4)*
  - Google, Uber,….
- *Levels of vehicle automation definition by National Highway Traffic Safety Administration (NHTSA) www.nhtsa.gov/staticfiles/rulemaking/pdf/Automated_Vehicles_Policy.pdf

Automotive Safety Systems (2/2)

- Connectivity based convenience & safety applications are becoming standard

- Current system are location-aware connectivity solutions
  - GNSS - Position & time
  - Cellular – Connectivity & time
  - Aided by other vehicle sensors
    - Wheel speed, gyro & accelerometer, steer/brake/transmission sensors

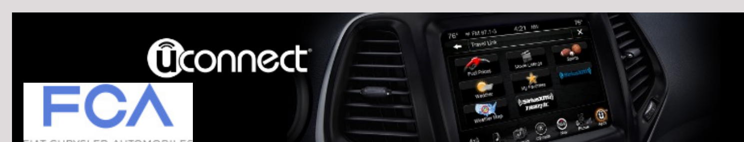



OnStar

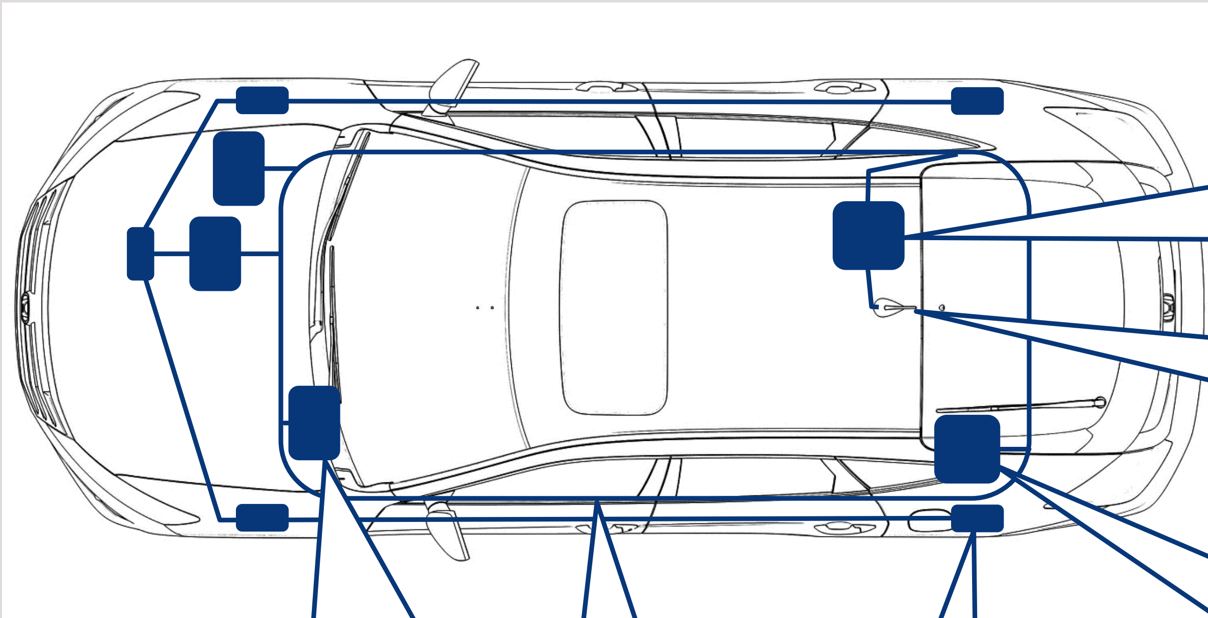
- Offer convenience & safety applications
  - Navigation
  - Emergency response
  - Diagnostic / prognostic /maintenance functions
  - Concierge services

Ford | SYNC

- Customer expectations
  - Connectivity
  - Road level location awareness (~5 m)
  - Some outages are expected
    - Cellular coverage
    - GNSS & position availability / accuracy



Automotive System Architecture



Connectivity Device

- Gateway for all outside connectivity
- Standard cellular modem (i.e. 4G / 3G)
- May have direct connections to Telematics ECU and/or HMI (Human – Machine Interface)
- User device may be used as the Connectivity Device

Vehicle Antenna

- Typically contain multiple services: Cellular, GNSS, XM, other
- Typically a single enclosure antenna
- Styling considerations are important

Telematics System / Device / ECU

- Controls all telematics functions
- Retrieves vehicle data from CAN
- May be integrated with the Connectivity device
- May interface / control HMI / User Interface / Cluster

ECUs – Electronic Control Units

- May be directly or indirectly connected to CAN

Control Area Network - CAN

- Communication medium between different ECUs, sensors and other modules
- Access may be controlled
- Messaging protocol may be unique to make, model & year

Sensors & Actuators

- Examples: Wheel Speed, Gyroscopes, Accelerometers

Challenges

- New technologies are likely be added to existing systems
  - Industry may adapt V2X / Connected Vehicle technology as an add-on
  - In most cases integration may not involve a complete system redesign

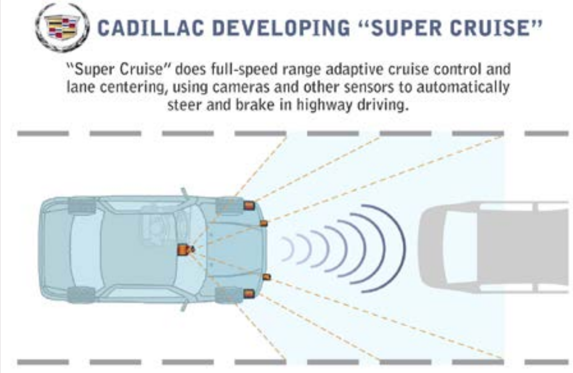
- Some systems may need to do redesigned
  - Antenna design and placement
  - Dedicated sensors may be needed for some functions
    - Positioning & navigation: Existing sensors are integrated (typically loosely coupled) in current systems
  - No requirements around reliability, integrity and jamming

- Challenges unique to automotive
  - Design driven by styling, cost and complexity
  - Automotive design cycle is typically 3-4 years & design life is around 8 years*
  - Significant work is needed to widely utilize Over-the-Air (OTA) update capability

* www.consumerreports.org

Industry Expectations of GNSS

- Legacy
  - Road level positioning: Which road am I in ?
  - May use existing sensors for aiding
- Today
  - Lane level positioning: Which lane am I in ?
    - Lane guidance: GNSS with corrections & maps
    - V2X / Connected Vehicles
  - May use existing & new dedicated sensors for aiding
    - Camera, radar
- Beyond
  - Better than lane level positioning
    - Automation
  - Multiple sensors will have to be integrated
- GNSS still remains the only viable absolute positioning & timing source
- Industry expectation on GNSS needs to change
  - Accuracy: few meters > centimeters
  - Availability: most of the time > all the time
  - Reliability: System failure detection is critical

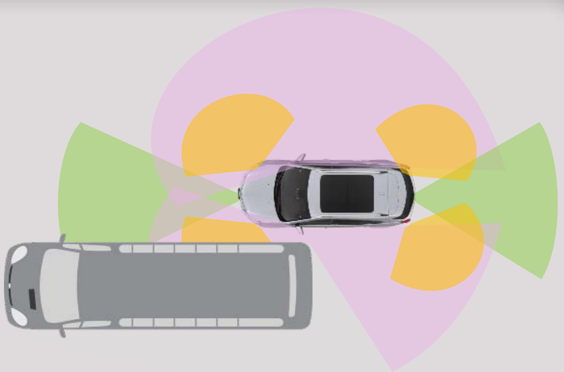


GM Super Cruise

Tesla Auto Pilot

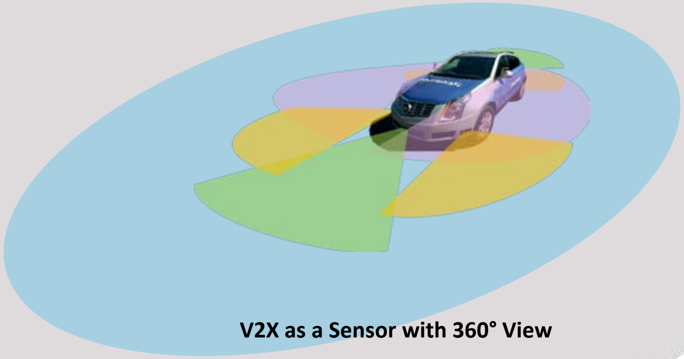
Why V2X / Connected Vehicles?

- Traditional sensors have their limitations
  - Occlusion of view
  - Sensor limitations: Rain, fog, lighting level/direction
  - Predicting driver and pedestrian intent / signal controls
- V2X / Connected Vehicles advantage
  - Enables real-time information sharing
  - Address most traditional sensor limitations
- Over a decade of R&D
  - FCC designated 5.9 GHz band in North America in 1999
  - Based on 802.11p Dedicated Short Range Communications (DSRC)
  - Established Over-the-Air (OTA) messaging protocols
  - USDOT funded over 10 years of R&D
    - http://www.its.dot.gov/research.htm
  - Anticipated USDOT mandate starting around 2022
  - May be supplemented by cellular technology *



Sensor Limitations: Occlusion of View

Sensor Limitations: Lighting Conditions

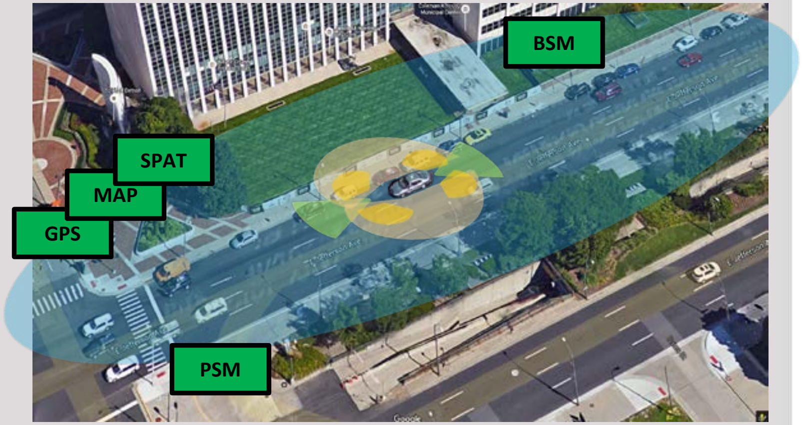


V2X as a Sensor with 360° View

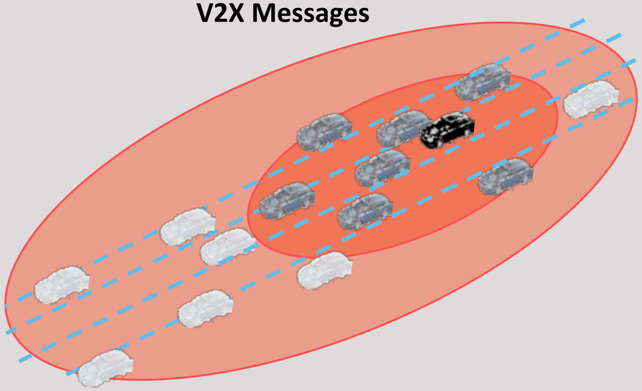
* End-to-end communication latency & throughput may need 5G technology to support all V2X use cases

Basics of V2X

- All road users exchange information
  - Vehicles broadcast Basic Safety Messages (BSM)
  - Pedestrian devices broadcast Pedestrian Safety Messages (PSM)
  - Traffic control devices also broadcast information
    - SPAT – Signal Phase & Timing
    - MAP – Intersection map
    - GPS – GPS / GNSS corrections
- Concept of Operation
  - Vehicles broadcast absolute position & time
  - Classify vehicles as:
    - Traveling in same direction, opposite or other
    - Same lane or adjacent lane
  - Identify threats & generate warnings
- Typical accuracy requirements
  - Road level: better than 5 m absolute
  - Lane level: better than 1.5 m absolute



V2X Messages



Concept of Awareness Zones

- **Minimum performance requirements for V2X vehicle / onboard equipment (SAE 2945/1), On-Board System Requirements for V2V Safety Communications, http://standards.sae.org/j2945/1_201603/**
- **Over-the-Air (OTA) message specification for V2X (SAE J2735), Dedicated Short Range Communications (DSRC) Message Set Dictionary, http://standards.sae.org/j2735_201603/**

V2X Over-the-Air (OTA) Messaging

- Defined in SAE J2735 DSRC Message Set
  - SAE – Society of Automotive Engineers
- Sent every 100 msec / 10 Hz
- Vehicle Position information
  - Time mark (GPS used as source)
  - Global coordinates
  - Accuracy estimate
- Motion / Heading / Acceleration
  - Others can predict future trajectory
- Control status
  - Others are made aware of intentions (i.e., lane change)
- Optional data can be added

Basic Safety Message (@ 10 Hz)

POSITION	MOTION	CONTROL	
Time	Speed	Brake	Temp ID
Latitude	Heading	Steering	Message Type
Longitude	Acceleration	Throttle	Vehicle Size
Elevation		Exterior Lights	

Optional Messages (Variable Rate)

- Event Notifications
- Vehicle Trail
- Vehicle Path Prediction
- **GNSS Measurement Data (RTCM*)**

Proprietary Optional Messages (Variable Rate)

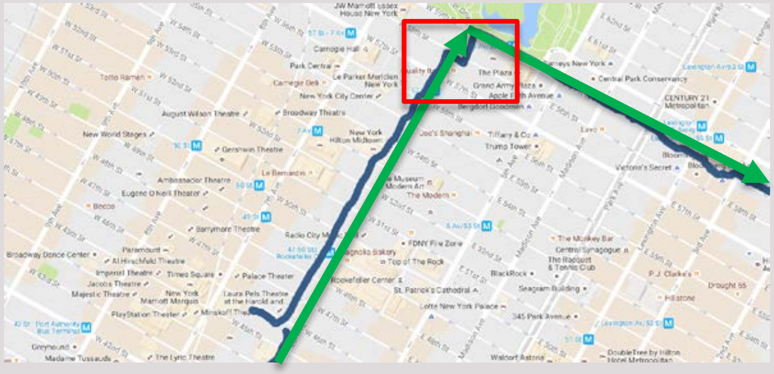
* Radio Technical Commission for Maritime Services (RTCM)

Renesas V2X Demonstration Platform

A Challenge for GNSS Industry….

- USDOT funded Connected Vehicle Pilots (CVP) starting in 2017
  - Includes sites in New York, Wyoming & Florida
  - http://www.its.dot.gov/pilots/
- First exposure of V2X to deep urban canyons
  - Serious GNSS availability & multipath issues
  - Augmentations can help but performance, affordability, and complexity challenges remain
  - GNSS integrity, reliability and jamming/ spoofing not in scope yet

6th Avenue NY Skyview



GNSS Only Data from 6th Ave New York (Connected Vehicle Pilot Site)

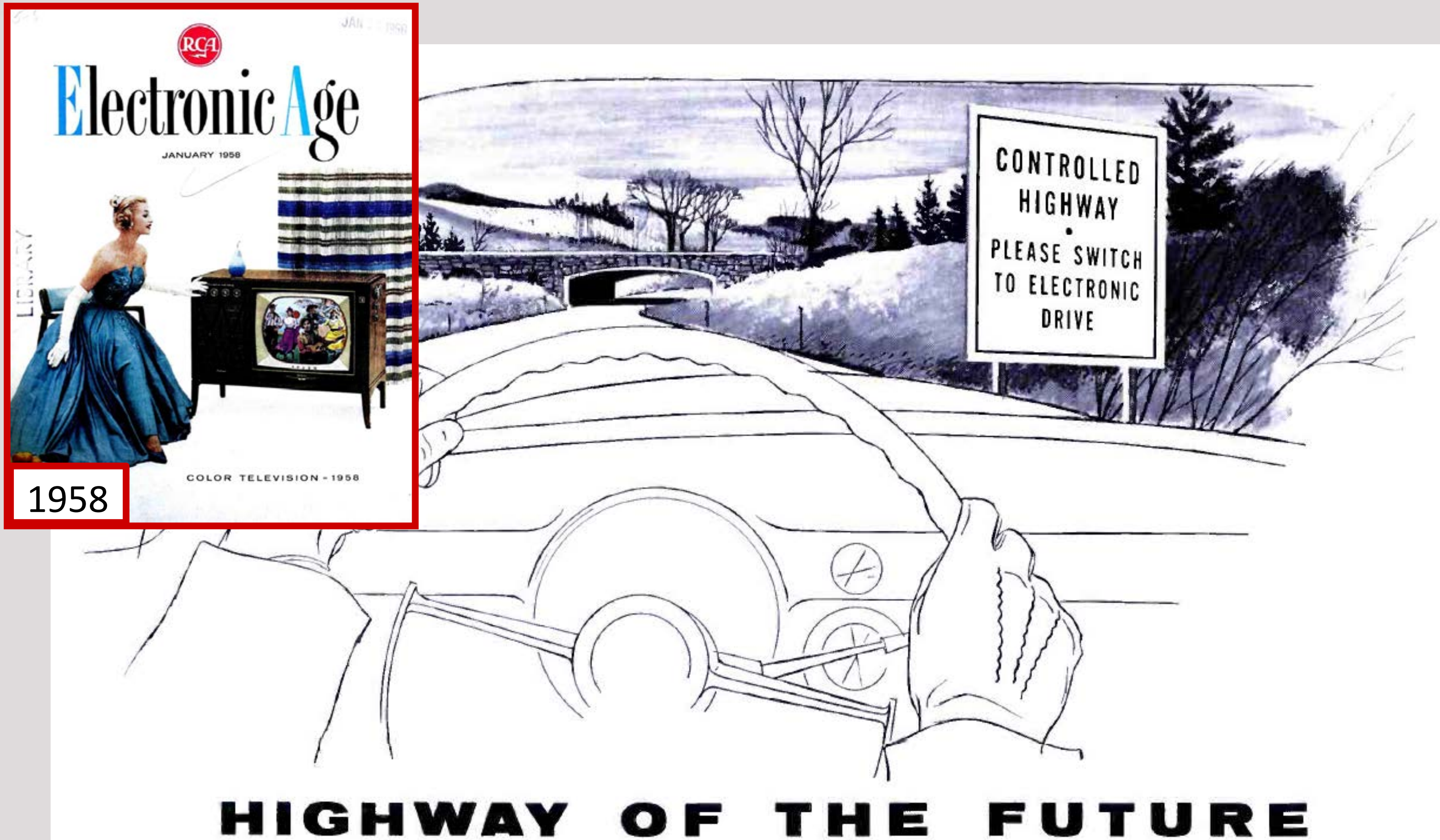
Source:
Data courtesy of eTrans Systems
Maps: Google Earth & Maps

Part I: Quantifying Navigation Safety of Autonomous Cars

Sensor Safety Metrics and Requirements
for Autonomous Passenger Vehicles (APVs)

Mathieu Joerger
Assistant Professor
The University of Arizona

APVs Around the Corner… in 1958



[IEEE Spectrum] Evan Ackerman , "Self-Driving Cars Were Just Around the Corner—in 1960", IEEE Spectrum Magazine, September 2016

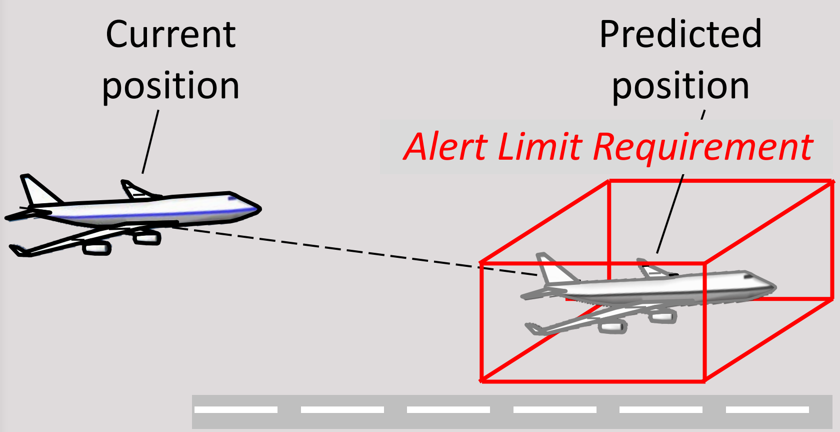
Scope of Current APV Research Efforts

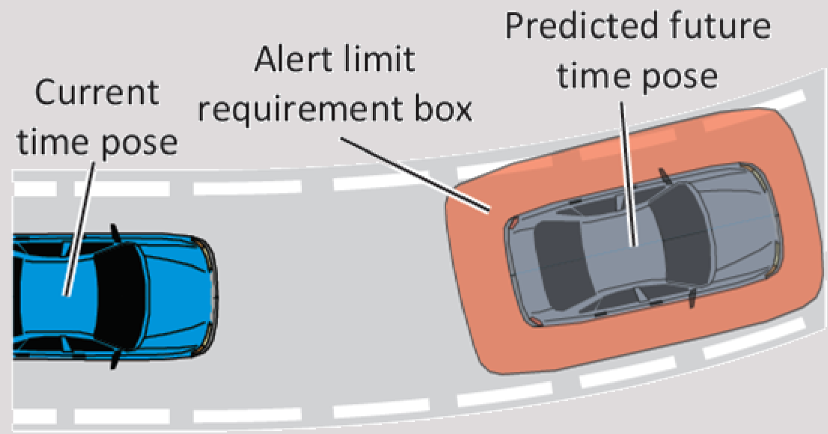
- Current approaches to APV safety
  - focus on Level 3 APVs:
    (Limited Self-Driving Automation)
    driver expected to take over at any time
  - are mostly experimental:
    - e.g., Google: **2 million urban** road miles; at fault in one (1) collision (02/16)
    - e.g., Tesla: **130 million highway** miles driven by autopilot, one fatality (05/16)

- Human drivers in the U.S. achieve **1 fatality per 100 million mile driven**
- A purely **experimental** approach is **not sufficient**
  - in response, **leverage analytical methods** used in aircraft navigation safety
  - In 'Federal Automated Vehicles Policy' (09/16), NHTSA mentions aviation safety

[NHTSA '14] fars.NHTSA.dot.gov, "Fatality analysis reporting system. Technical report, National Highway Traffic and Safety Administration," 2014

Leveraging Methods Used in Aviation

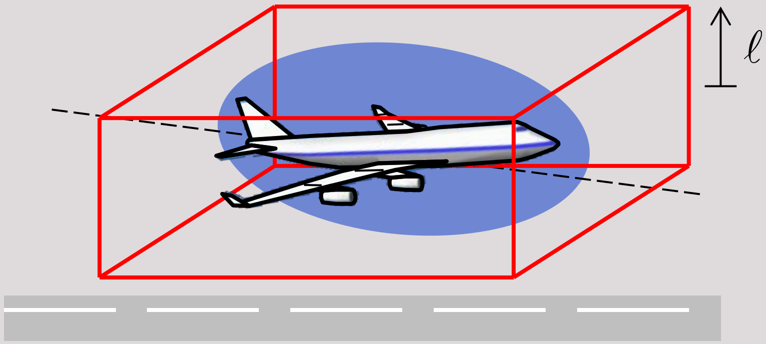


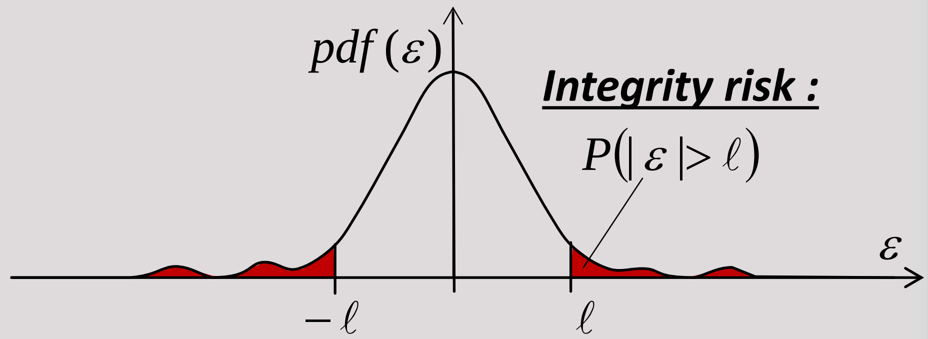


- It took decades of R&D to bring alert limit down to tens of meters [WAAS]
- Challenges in bringing aviation safety standards to APVs
  - GPS-alone is insufficient → **multi-sensor** system needed
  - not only peak in safety risk at landing → **continuous risk monitoring**
  - unpredictable meas. availability → **prediction** in dynamic APV environment

[WAAS] RTCA SC-159, "Minimum Operational Performance Standards for GPS/Wide Area Augmentation System Airborne Equipment," Doc. RTCA/DO-229C, 2001.

Aviation Safety Metrics

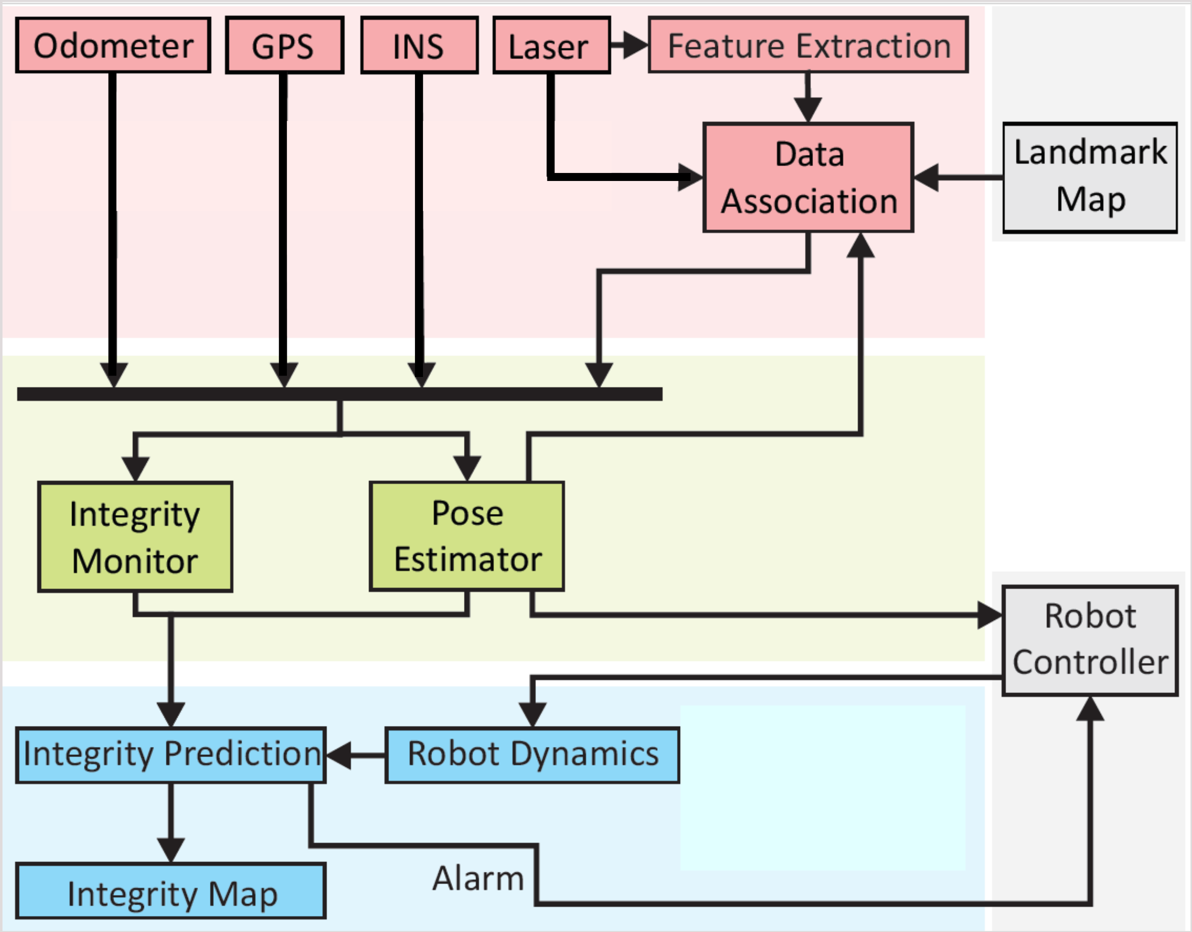




- Accuracy: typically a **95%** requirement
- Integrity: measure of **trust** in sensor information
  - in aviation, up to **1-10^{-9} per operation** requirement
  - integrity risk = risk of unacceptably large pose error without a timely warning
- Continuity: about **1-10^{-6} per operation** requirement
  - continuity risk = risk of unscheduled interruption
- Availability: fraction of time where accuracy/integrity/continuity are met

Example APV Safety Evaluation

- Evaluate safety risk contribution of **each system component**



Ask the Experts – Part 1

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The University of Arizona

Jonathan Auld
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Poll #2

In your opinion, what is the most important technology in an autonomous car? (Please select your top two)

- *Cameras*
- *Lidar/Radar*
- *GNSS*
- *Inertial*
- *Map Matching*

Part II: Quantifying Navigation Safety of Autonomous Cars

Sensor Safety Metrics and Requirements
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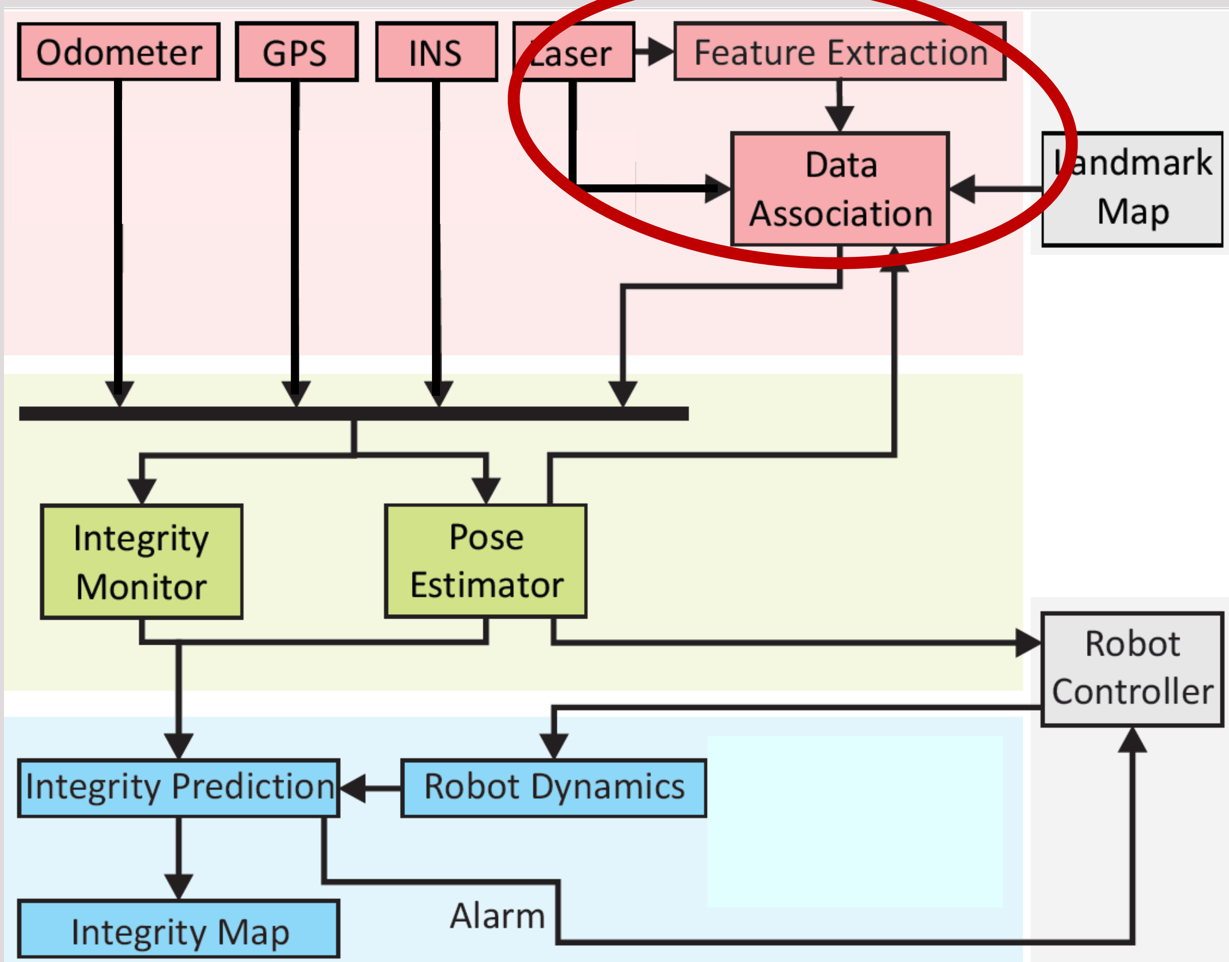
Example APV Safety Evaluation

- Evaluate safety risk contribution of **each system component**



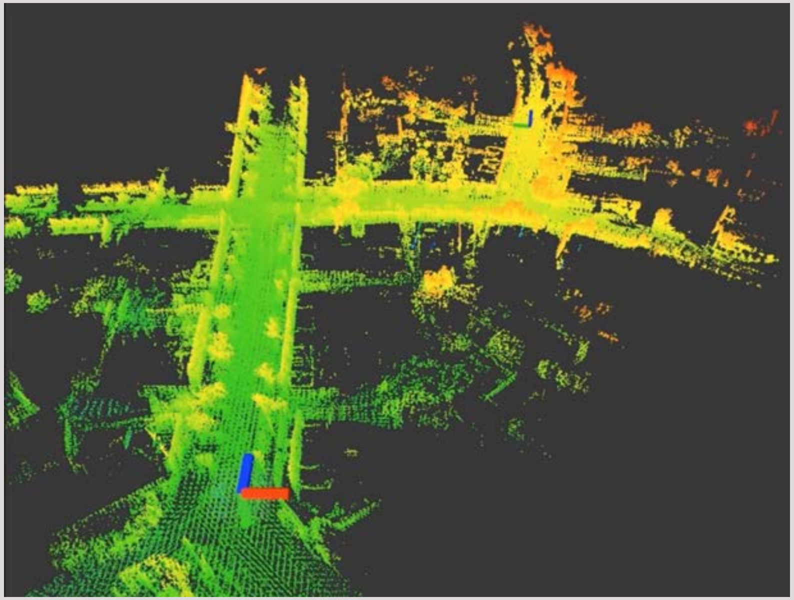
Laser Data Processing

- Each individual laser (radar) data point provides little information

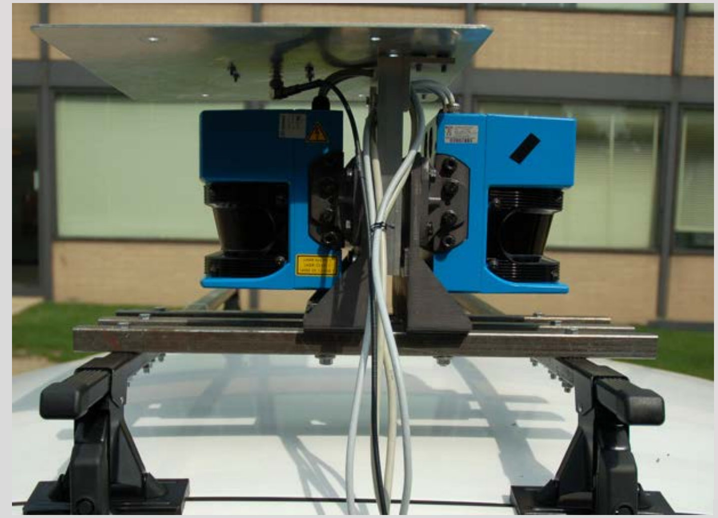
- Feature extraction
  - find few **distinguishable**, and **repeatedly identifiable** landmarks

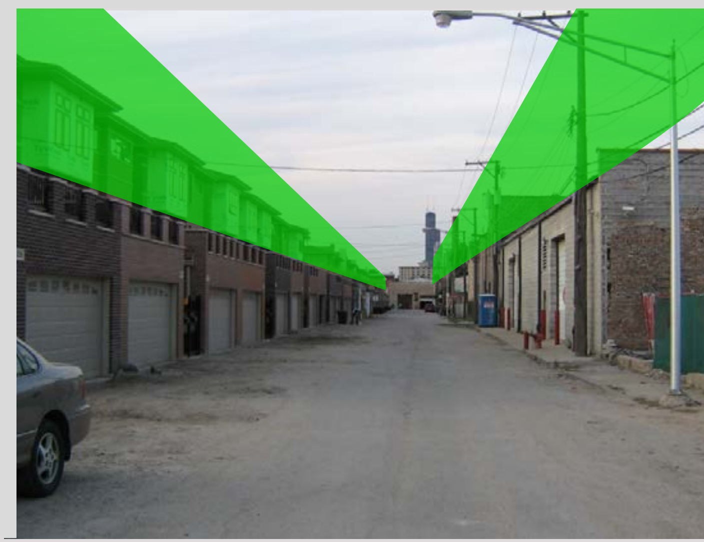
- Data association
  - from one time step to the next, find correct **feature in stored map corresponding to extracted landmarks**

[processed data from the KITTI dataset: http://www.cvlibs.net/datasets/kitti/]

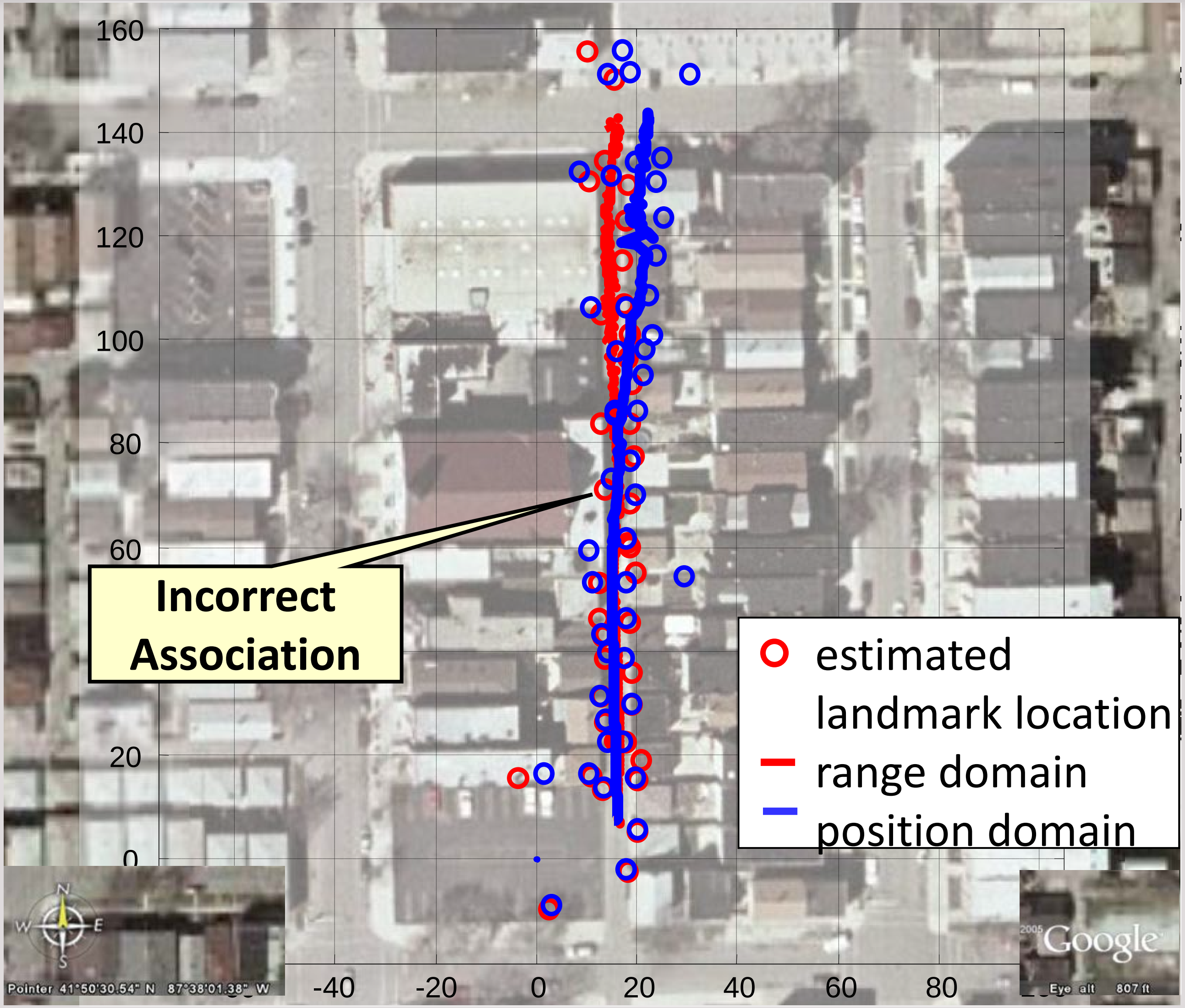


Experimental Setup

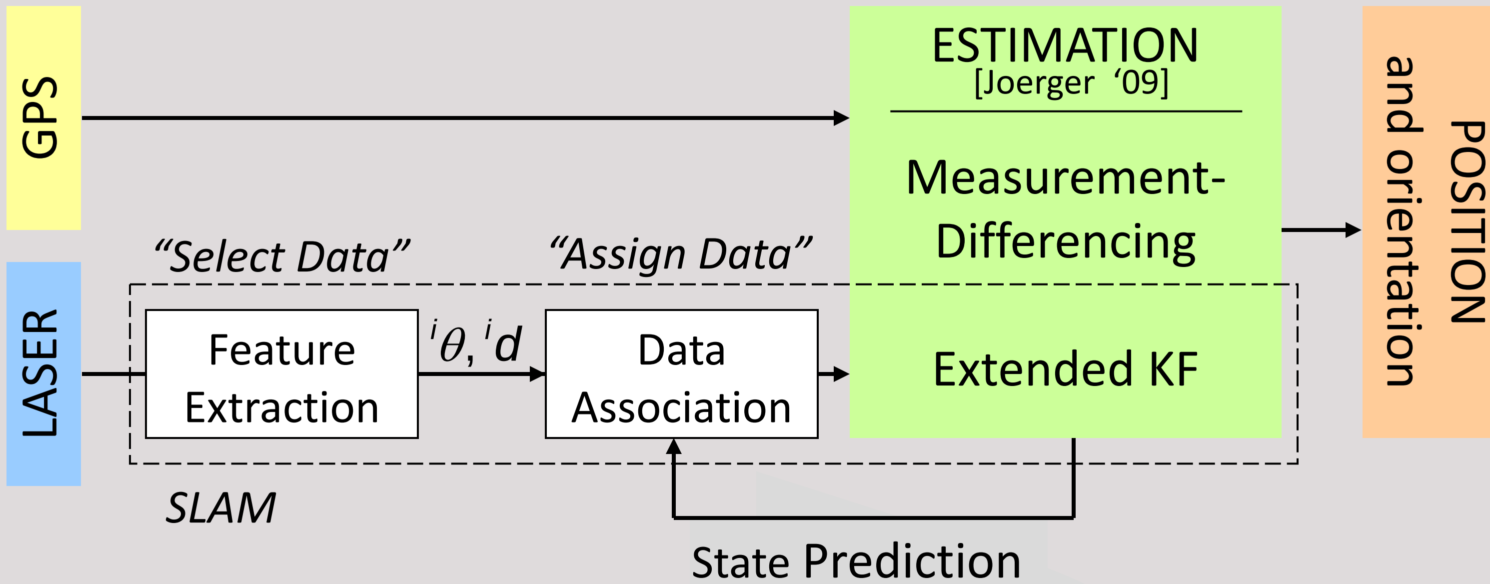


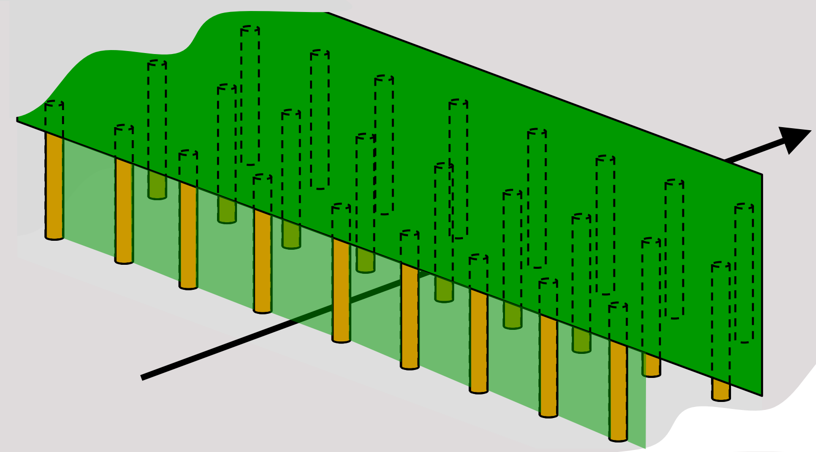


True Versus Estimated Trajectory



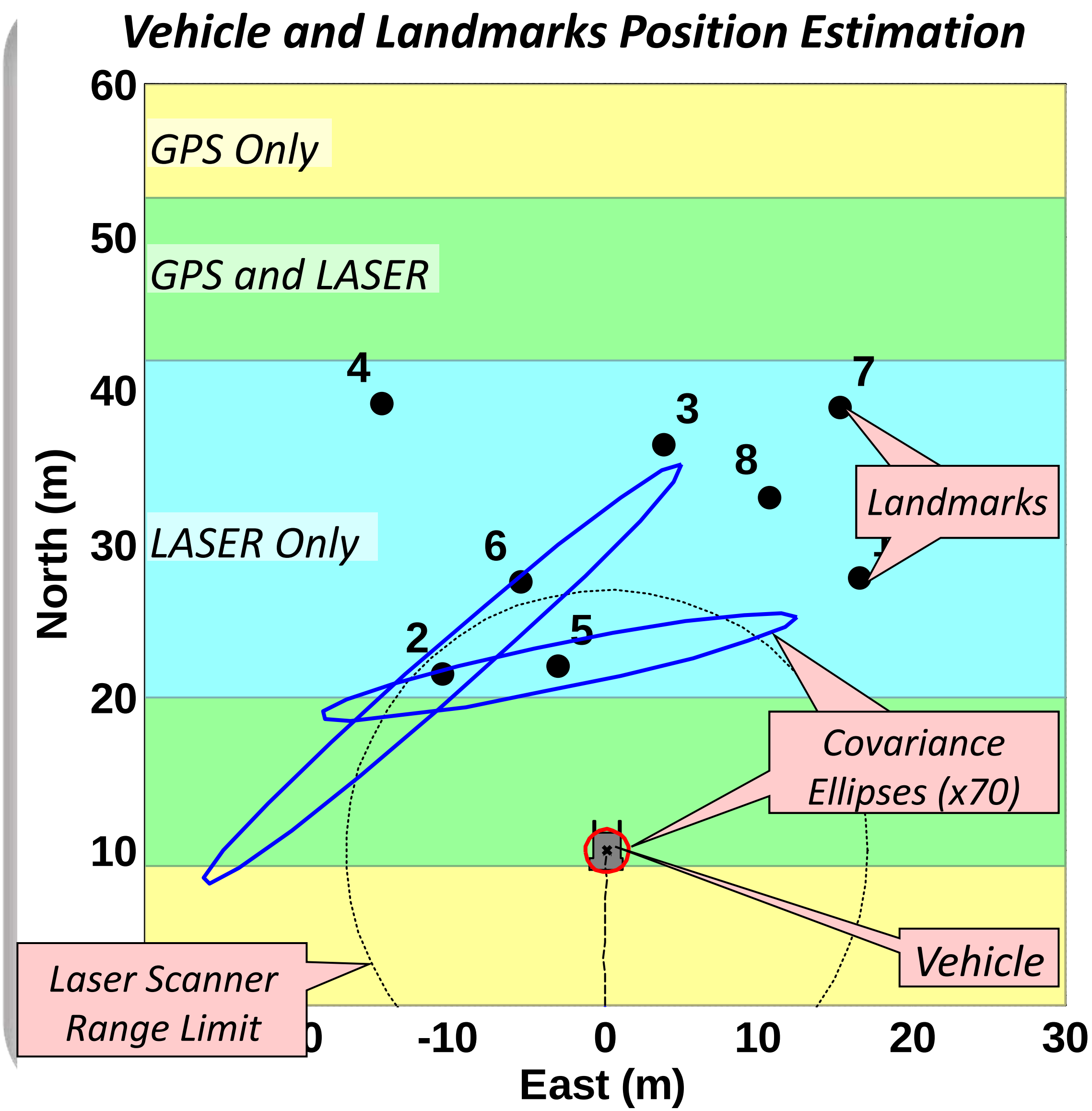
Multi-Sensor GPS/Laser System

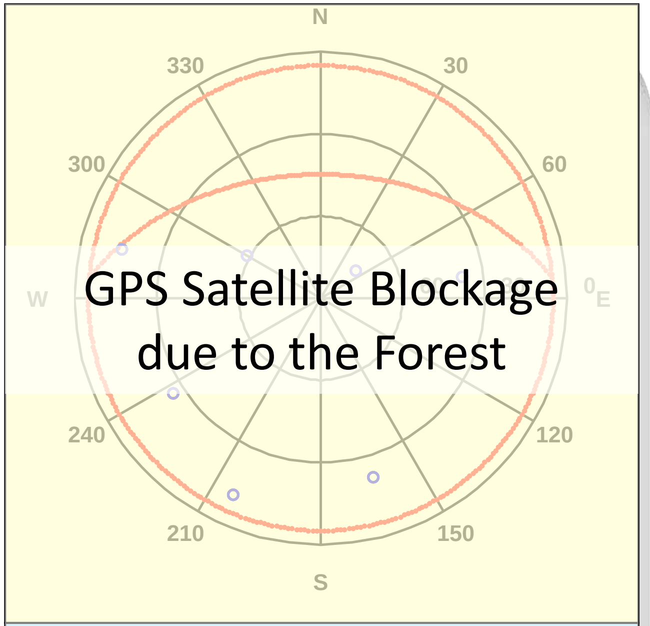


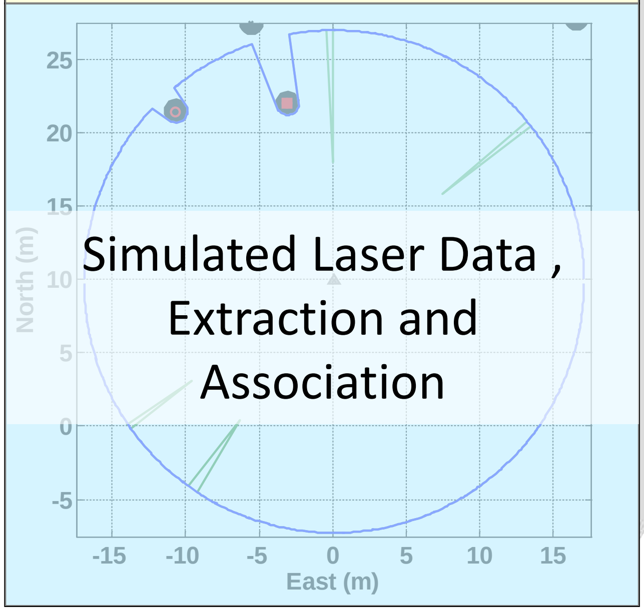


Simulation Scenario:
Vehicle Driving through Forest

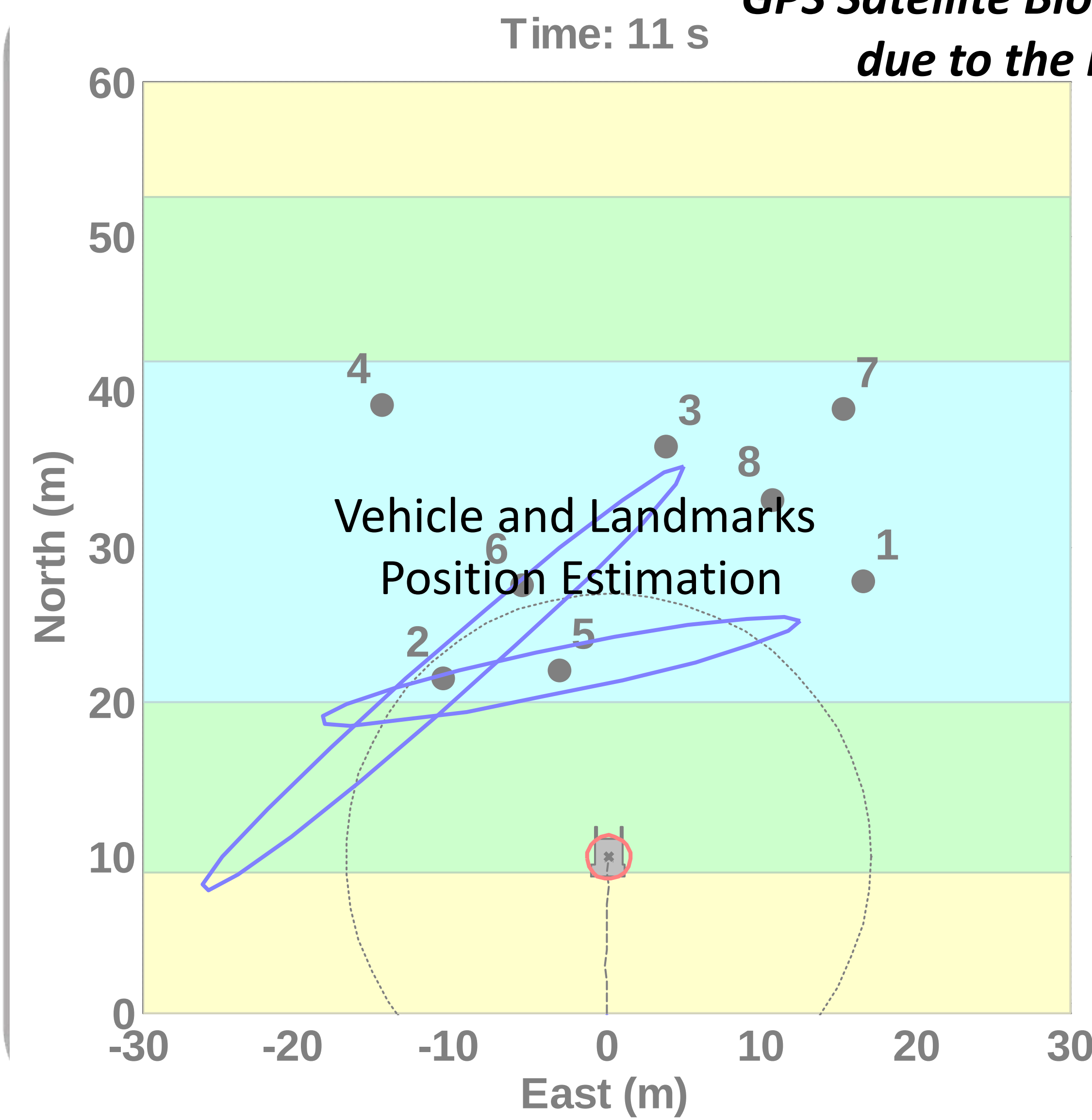
Direct Simulation of SLAM



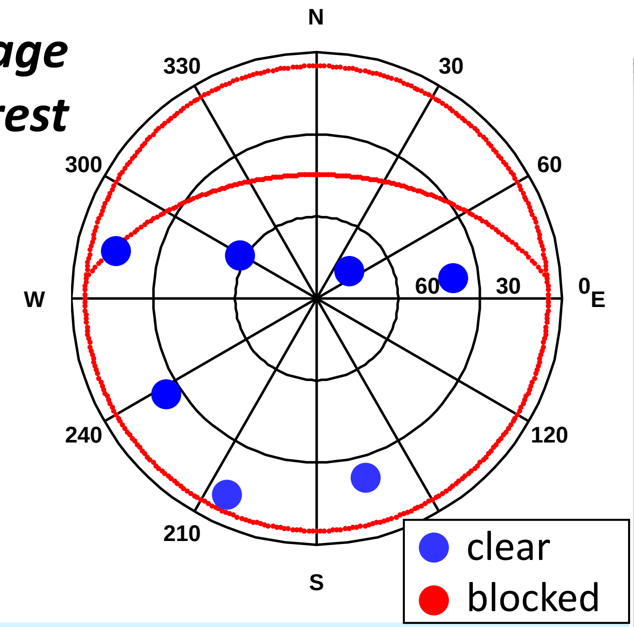


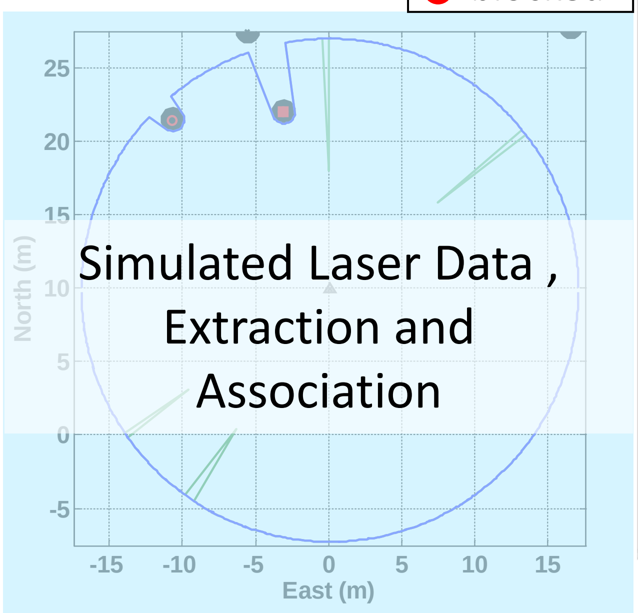


Direct Simulation of SLAM

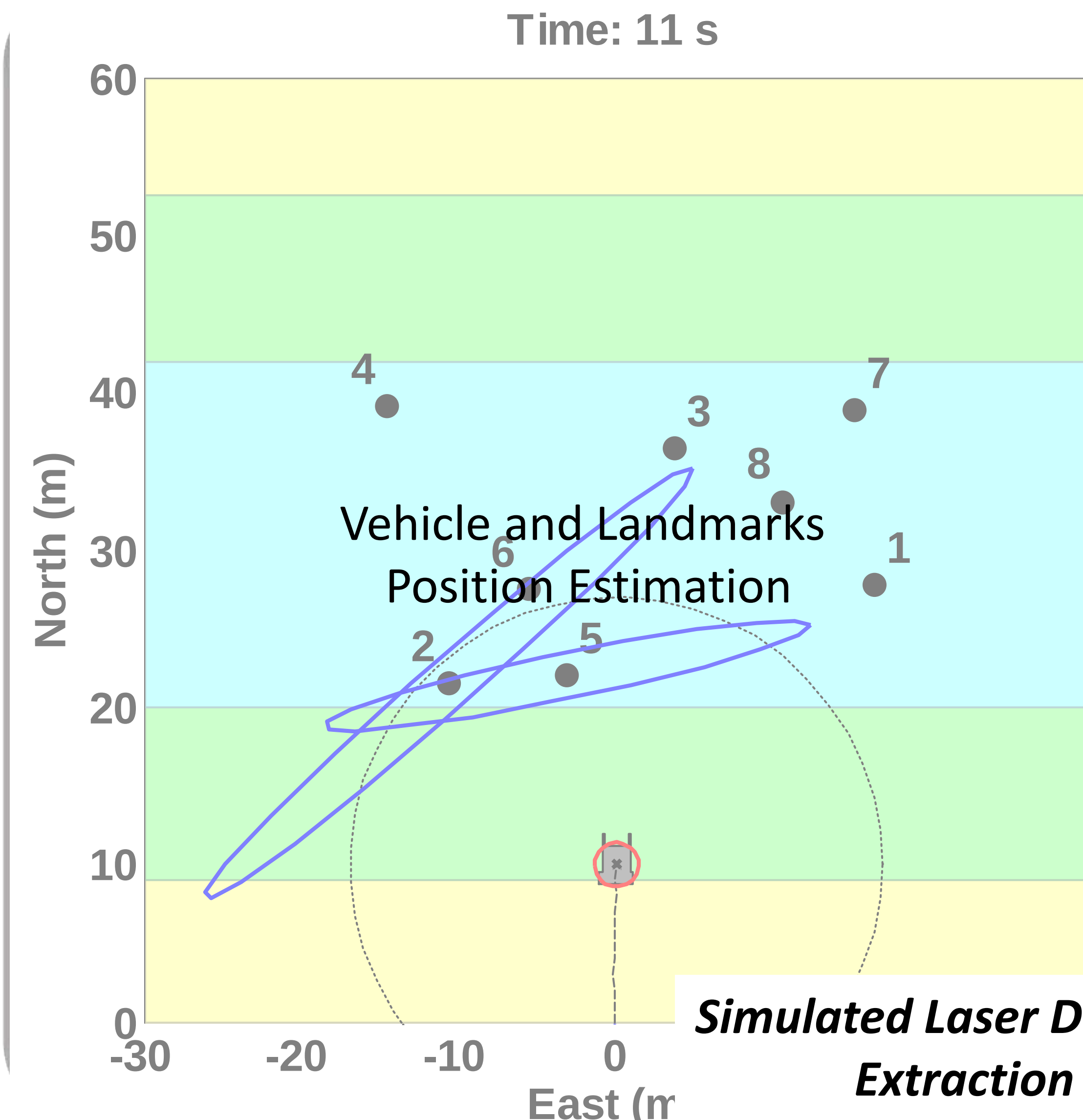


GPS Satellite Blockage due to the Forest

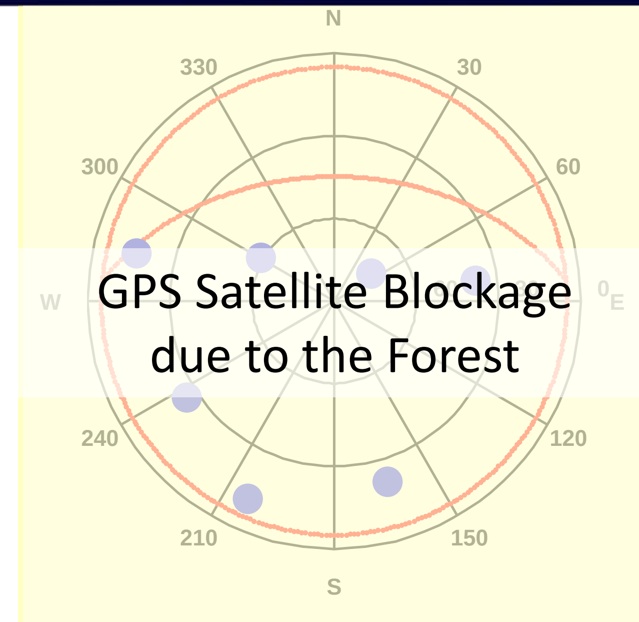




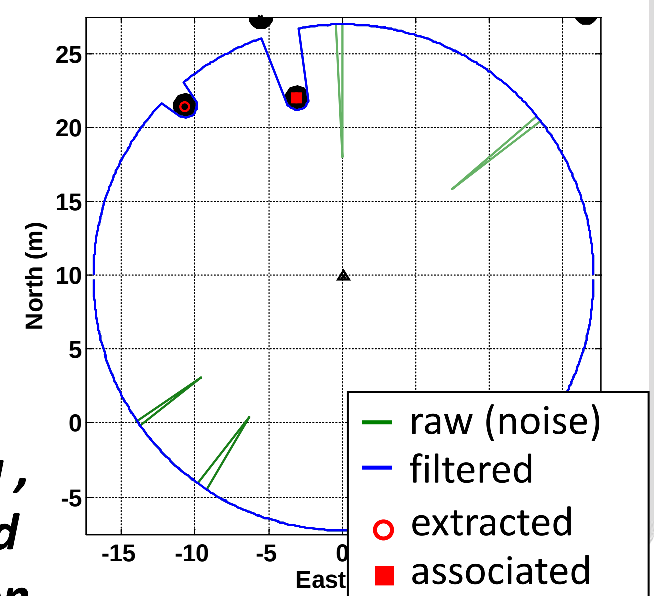
Direct Simulation of SLAM



Vehicle and Landmarks Position Estimation

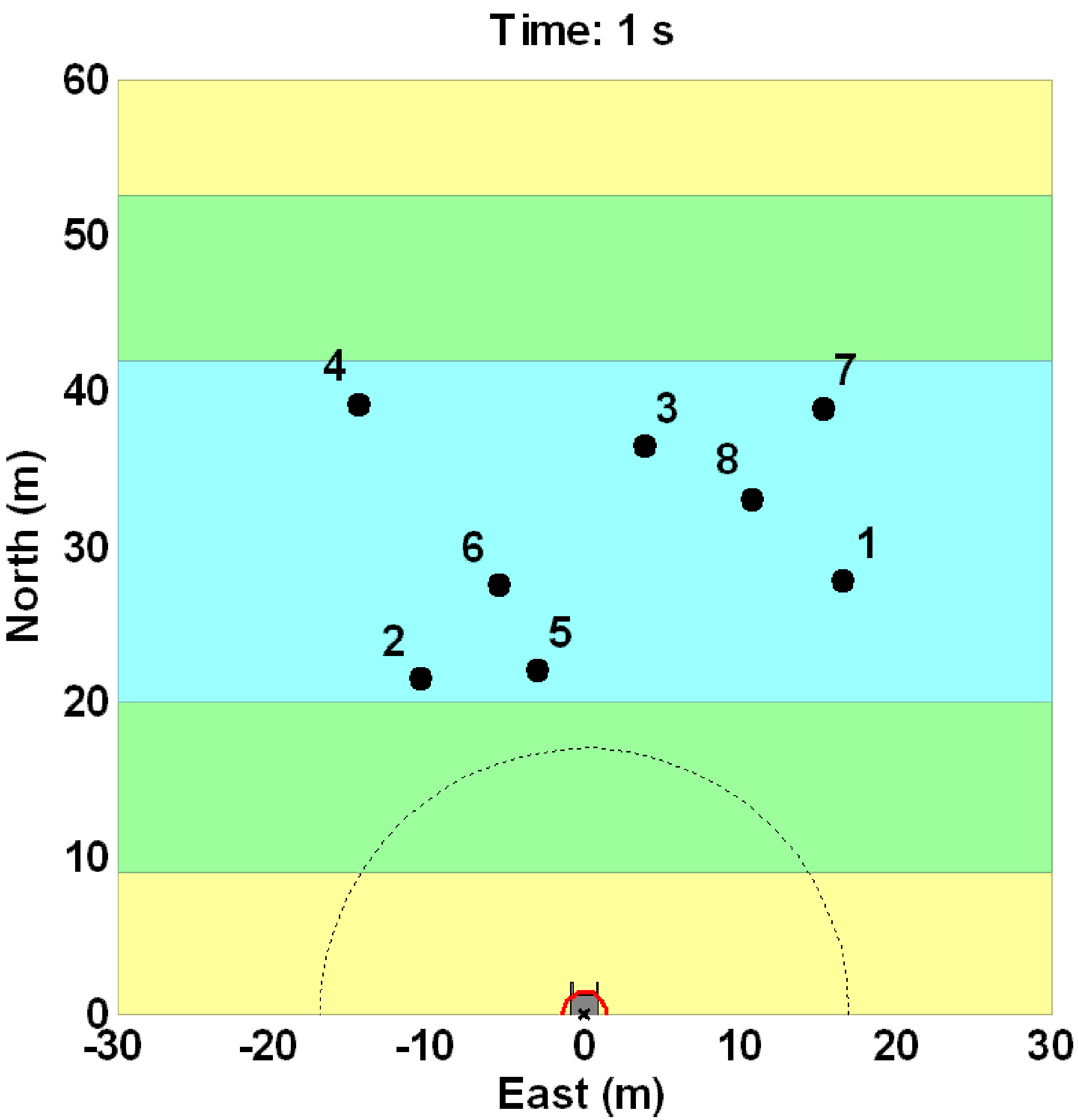


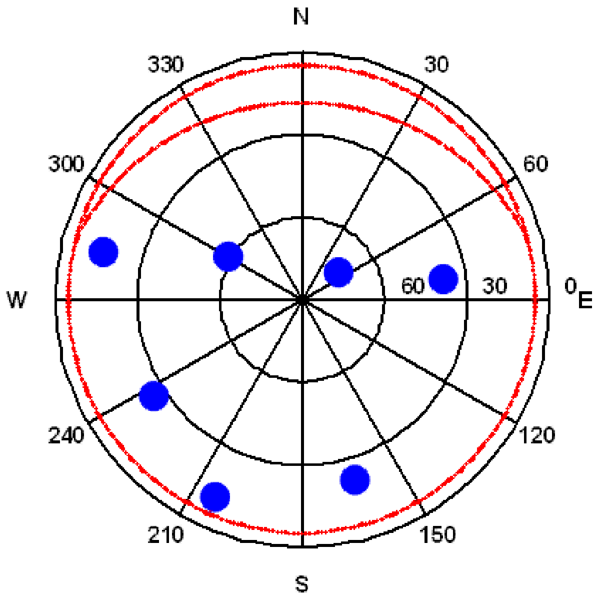
GPS Satellite Blockage due to the Forest

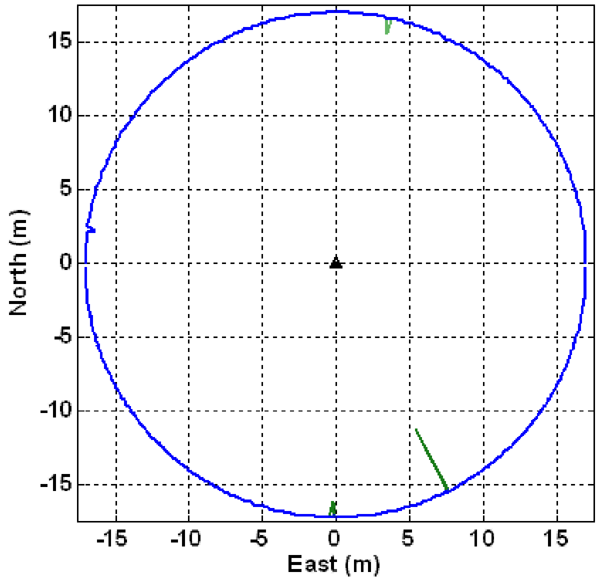


Simulated Laser Data , Extraction and Association

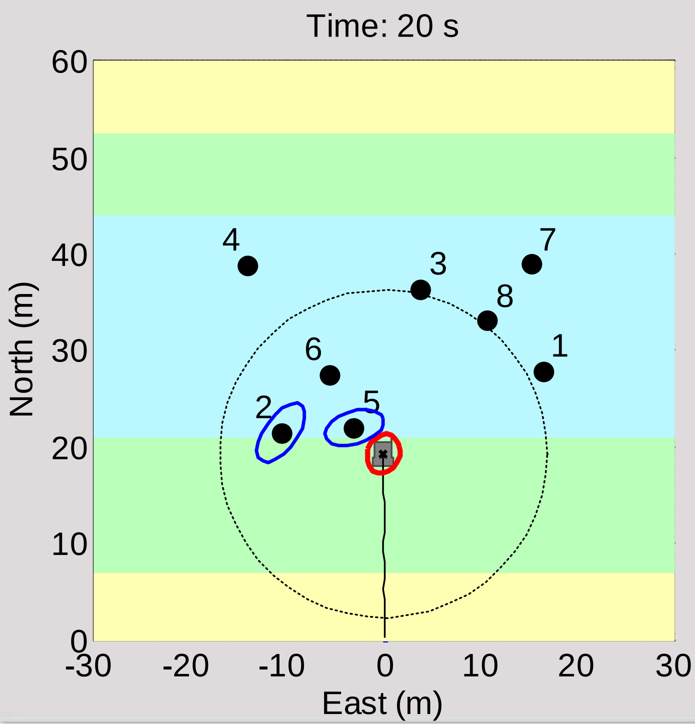
Direct Simulation of SLAM

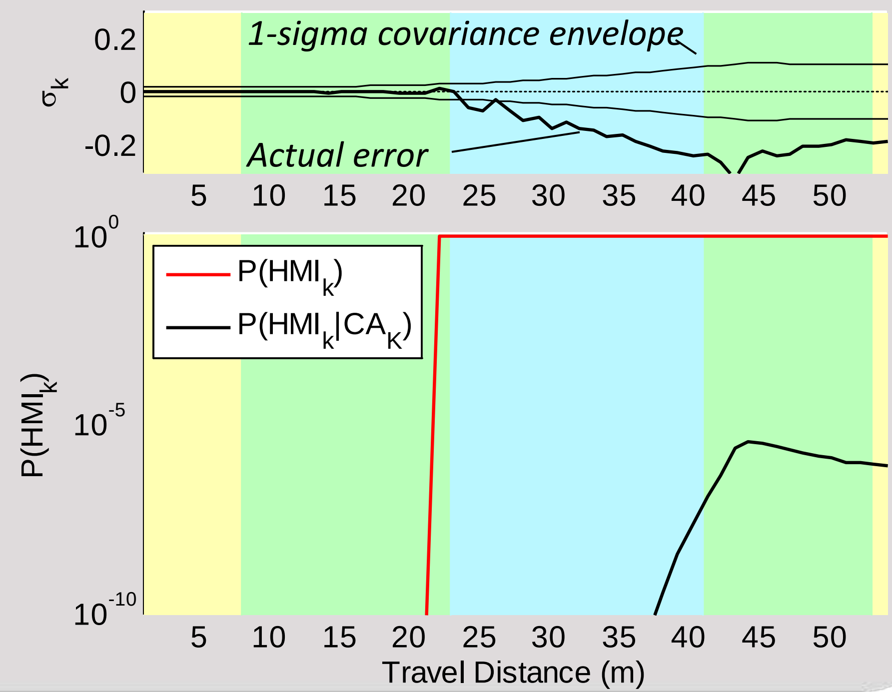






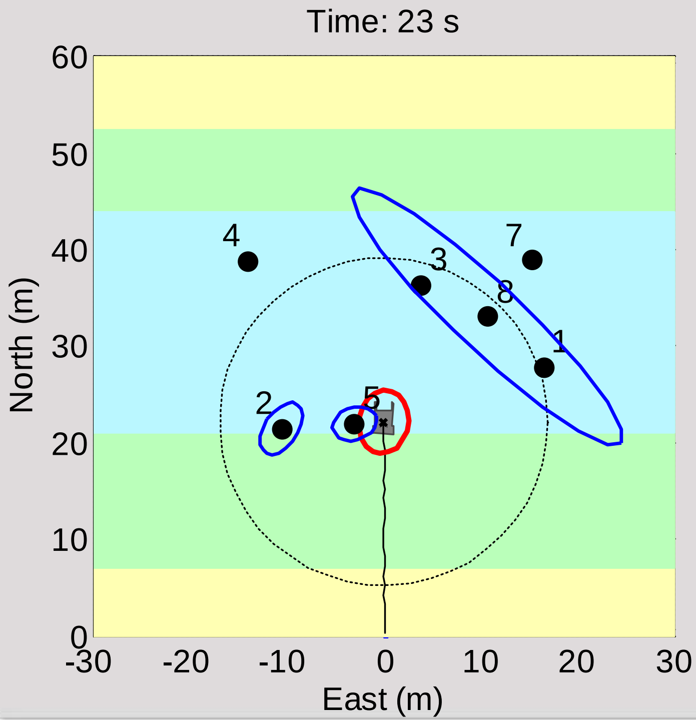
- The integrity risk bound accounting for possibility of IA **is much larger than risk derived from covariance only**
  - incorrect association occurs for landmark 6, which appears after being hidden behind 5

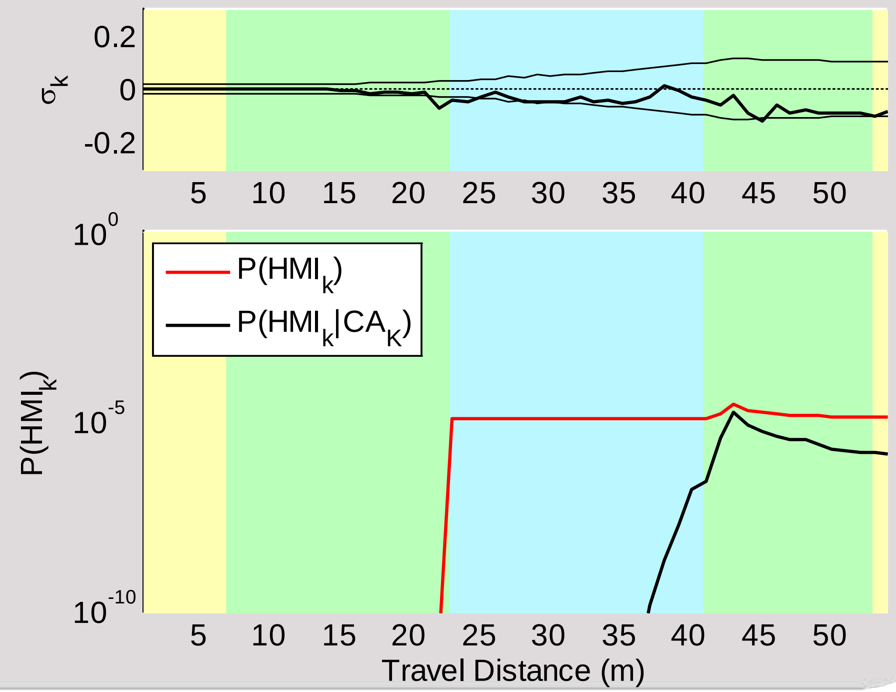




Direct Simulation of SLAM

- **Key tradeoff: Fewer extracted features**
  - **improve integrity** by reducing risk of incorrect association,
  - but **reduce continuity**





Conclusions

- Major challenges to analytical quantification APV navigation safety include
  - **safety** evaluation of **laser, radar, and camera**-based navigation
  - **multi-sensor** pose estimation, fault detection, and integrity monitoring
  - pose **prediction** in dynamic APV environment

- Analytical solution to APV navigation safety risk evaluation
  - could be used to set **safety requirements on individual sensors**
  - would provide design guidelines to **accelerate development of APVs**
  - would establish clear sensor-independent **certification** metrics

Safety Critical Development for High Precision GNSS in Autonomous Vehicles

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Director
Safety Critical Systems
NovAtel

NovAtel® Inc.

Hexagon AB

Positioning Intelligence

Global Positioning
Solutions and Services

Land

Air

Sea

High Accuracy and Reliability

- **Head office located in Calgary, Canada**
- **More than 400 employees**
- **Part of the Hexagon Group**
- **20+ Years in GNSS**
- **Market leader in our space with >50% market share.**

Trends in GNSS…..

InsideGNSS NovAtel inside unmanned systems

90s and early 2000s: Accuracy

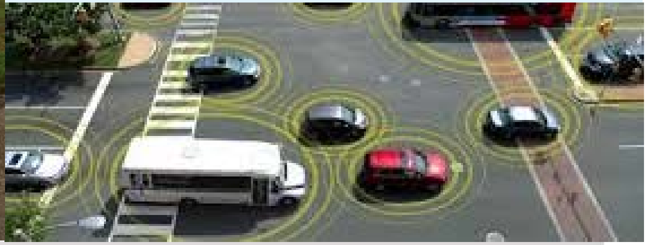
- Positioning techniques
- DGPS, RTK
- Multipath mitigation

Now: Availability

- Multi-constellation:
  GPS, GLONASS,
  Galileo, Beidou
- Sensor Fusion
- Position + orientation

Future: Safety & Reliability

- Safety of Life applications
- Functional Safety and Integrity
- Protection from spoofing/jamming



Increasing Demand for Safety in Guidance

IEC EN 61508

DO-178C

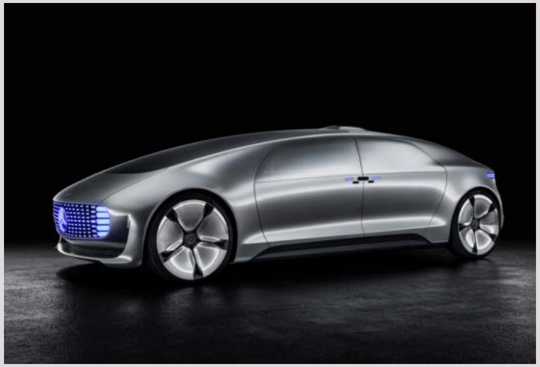
DO-254

DO-178C

DO-254

ISO 25119

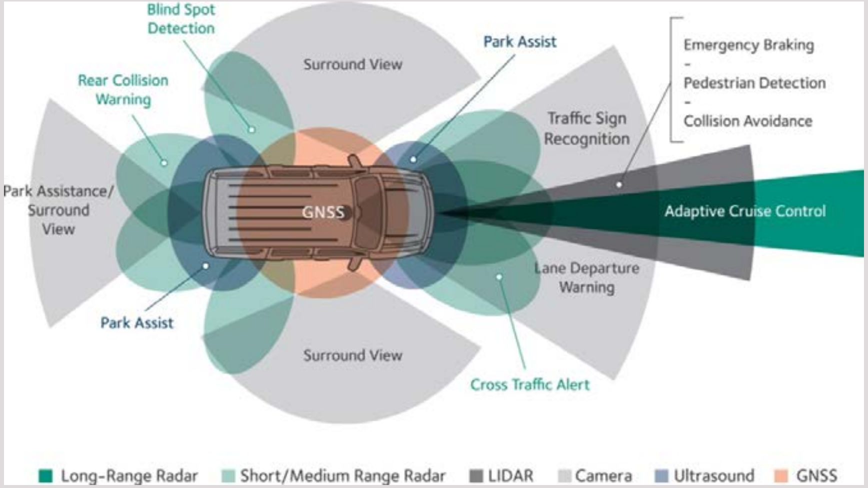
ISO 26262



EN 50126
EN 50128
EN 50129

How GNSS fits into automotive positioning

- GNSS will serve as the source of Absolute PVT to the autonomous driving challenge.
- An autonomous vehicle application will expect 100% availability in all conditions and locations
  - Urban, Rural, All Weather, All Visibility
- GNSS plays a critical role in this but cannot be the sole positioning source.
- A fusion of multiple sensors will be required with GNSS playing a key role. Time alignment of sensors as well as positioning.



GNSS in Automotive Today

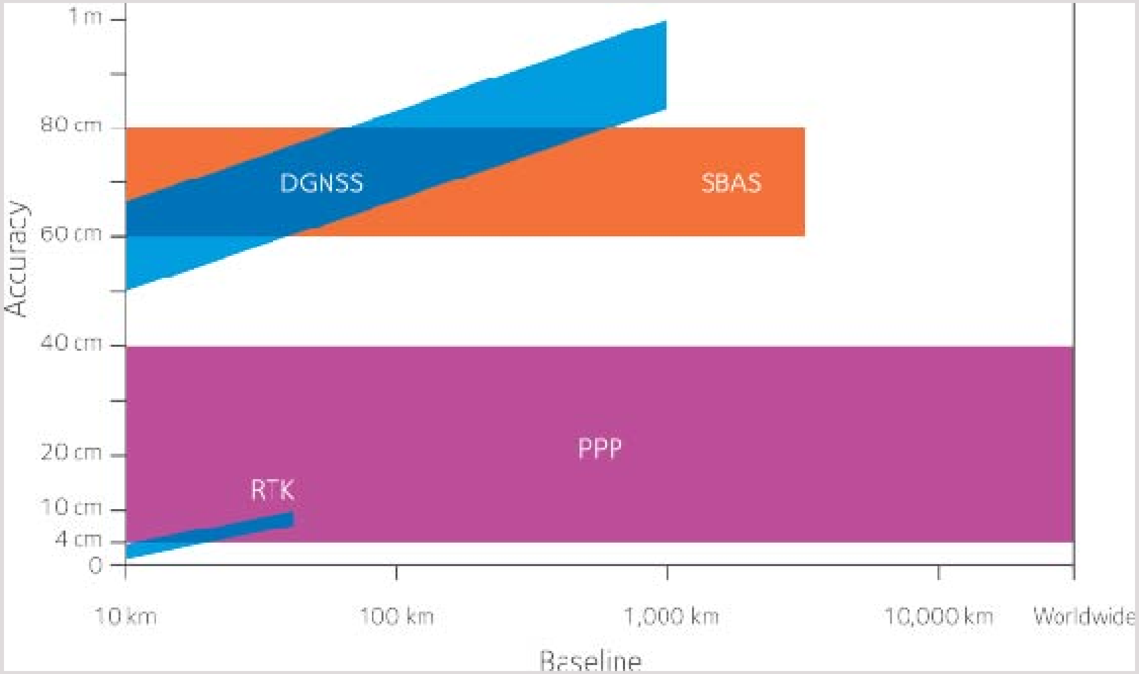
- Today the primary use case is positioning for navigation.
- Receivers are single frequency and support 1-2 constellations
- Narrowband RF and Antennas
- Accuracy - 2-5 meter level
- Data rate outputs <=10Hz
- Primarily pseudorange based positioning techniques, with some carrier phase assistance, in use.
- No functional safety standards
- No integrity data provided on the output solution
- Built to automotive manufacturing standards

GNSS requirements for autonomous driving

- Lane level accuracy - **<1 metre 3-sigma**
  - Data rate outputs > 10 Hz
  - **3D** Position and Velocity outputs
- Multi-frequency, Multi-constellation receiver **and** antenna
  - Improves overall accuracy
  - Required to assist in solution convergence time
  - Increases available measurements
- Supporting **PPP correction** service required over satellite and internet delivery.
- **Initial focus is on Highway/Freeway** with a transition to urban environments
- Functional Safety
  - **ISO26262** Development
  - **Integrity** outputs to support protection levels
  - **Authentication**

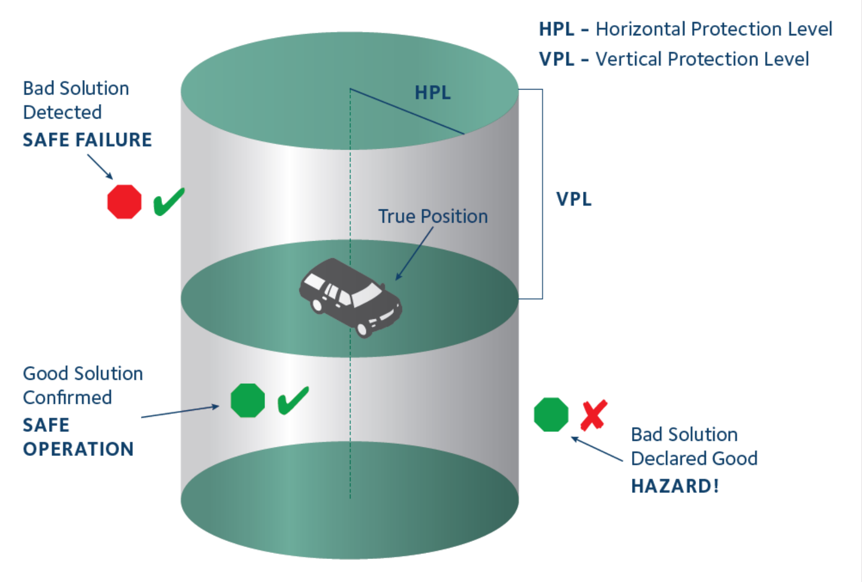
Positioning Technology Options

- To allow for ubiquitous positioning at the **decimeter** level we believe a **PPP** level of service is required.
- RTK is certainly more accurate (cm level) but infrastructure costs are high and unnecessary.
- PPP **convergence times** continue to be too long for the automotive market but R&D is well underway to resolve this current limitation.



Defining Safety for a Navigation System

- **Integrity** = degree to which you can trust the information being provided by a navigation system.
- **Continuity** = ability of any navigation system to execute its function through a specified time period or operation.
- **Accuracy** = degree to which the estimated solution from a navigation system conforms to the true solution.
- **Availability** = percentage of the time that a system can be used for navigation purposes



Functional Safety / Certification

InsideGNSS NovAtel inside unmanned systems

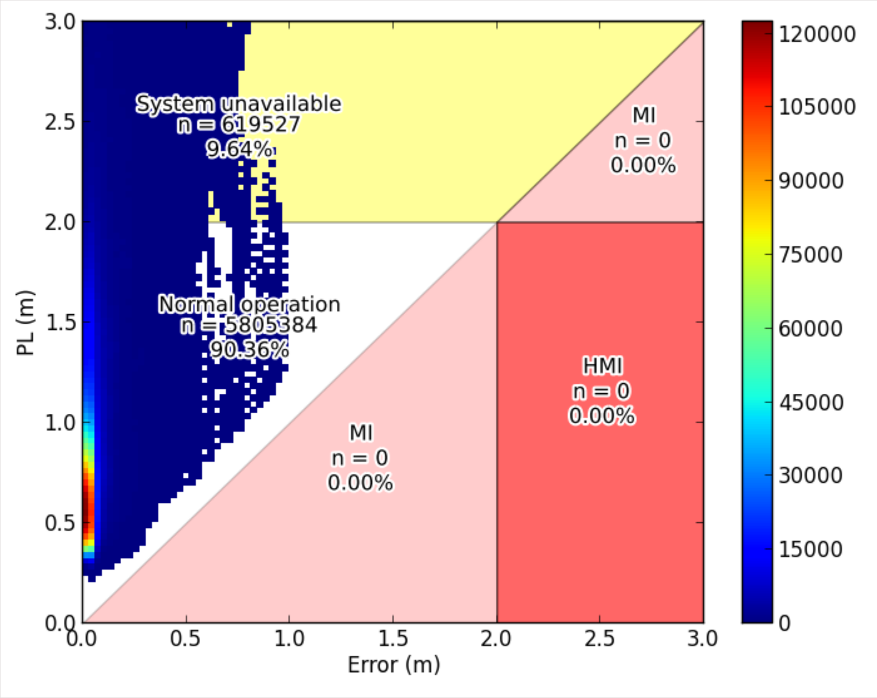
- Key challenge of making high precision GNSS applicable to autonomous vehicles is the safety requirements
- At the system level a safety case is developed and failure rates are allocated to sub systems
- Process and Development criteria for the Architecture, HW and SW needs to be compliant with industry standards and the applicable safety level.

Approximate cross-domain mapping of ASIL

Domain	Domain Specific Safety Levels				
Automotive (ISO 26262)	QM	ASIL-A	ASIL-B/C	ASIL-D	-
General (IEC-61508)	(SIL-0)	SIL-1	SIL-2	SIL-3	SIL-4
Aviation (DO-178/254)	DAL-E	DAL-D	DAL-C	DAL-B	DAL-A
Railway (CENELEC 50126/128/129)	(SIL-0)	SIL-1	SIL-2	SIL-3	SIL-4

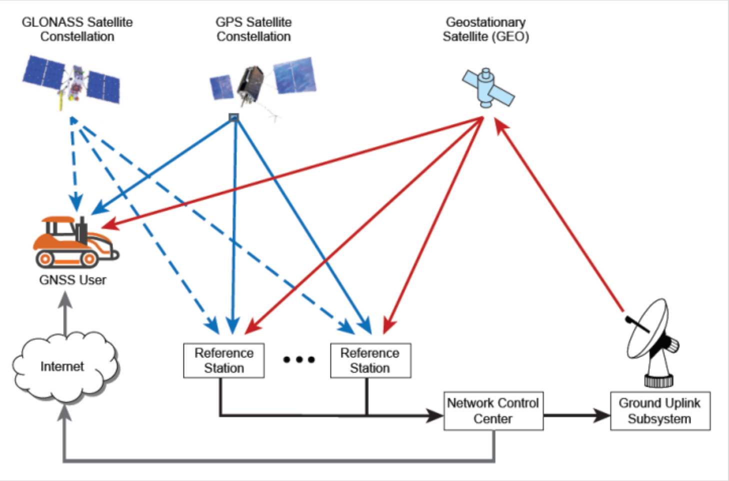
This comparison is from Wikipedia - http://en.wikipedia.org/wiki/Automotive_Safety_Integrity_Level

- The GNSS PVT must now be both **Accurate and Safe**
  - In all conditions (ex. poor multipath and/or low satellite count).
  - Probability of misleading info at the level of 10^{-6} to 10^{-7}/hr
  - Balanced with Availability
- **Integrity and Authentication** functions will be incorporated into PPP network
- Receiver burden will be higher than in aviation due to shorter time to alarm. RAIM techniques will need to be expanded to carrier phase positioning.



Summary of the Challenge

- Receiver and Antenna designed to hit automotive…
  - Safety and Quality requirements – ISO26262 and TS 16949
  - Cost and Volume – significantly different from current High Precision offerings
  - Styling – Antenna needs to fit the style requirements of the vehicle platform and still deliver the performance
  - PVT performance at the 1m 3-sigma level
- A correction network delivering data over satellite and internet globally with safety considerations designed in…
  - Acceleration of PPP convergence times
- Expansion of threat models and integrity analysis to the automotive use case



NovAtel's Team is working to solve all of these challenges!

Next Steps

Visit www.insidegnss.com/webinars for:

- PDF of Presentations

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Poll #3

In your opinion, what are the biggest challenges in autonomous cars (Please select your top two)

- *Confidence that users will adopt*
- *Sensor technology*
- *Connectivity/Cyber security*
- *Certification*
- *Cost*

Ask the Experts – Part 2

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