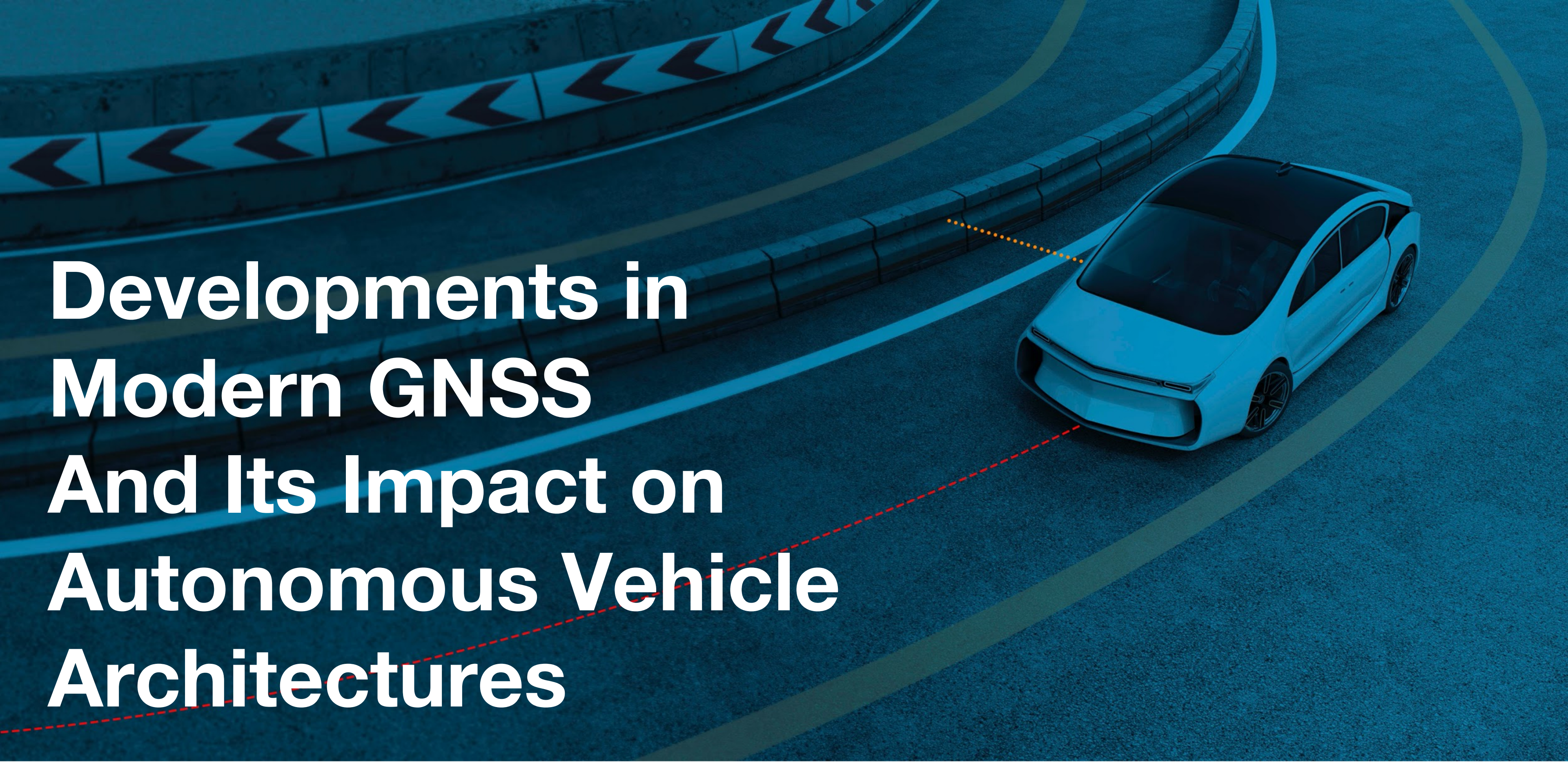


Developments in Modern GNSS And Its Impact on Autonomous Vehicle Architectures

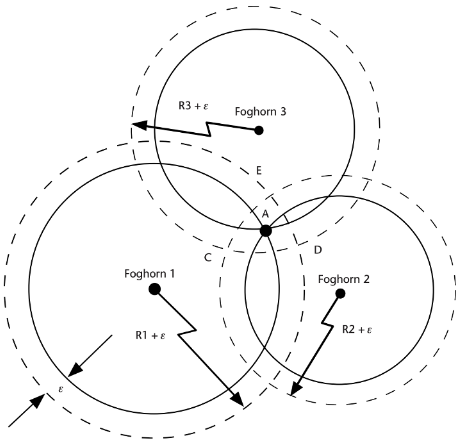
Niels Joubert, Tyler G R Reid, Fergus Noble
IEEE IV 2020

Perception is Key To Autonomy

But Unaided Perception Struggle To Solve Autonomy Safely and Reliably

GNSS-Based Localization Can Help

Limitations of Standard GNSS



Error Source	Magnitude
Ionosphere	~3 m
Troposphere	~1 m
Orbit Error	~2 m
Clock Error	~2 m
others	~1m

Provides Global Localization

Constellation of satellites transmits digital ranging codes that support accurate distance and time measurement

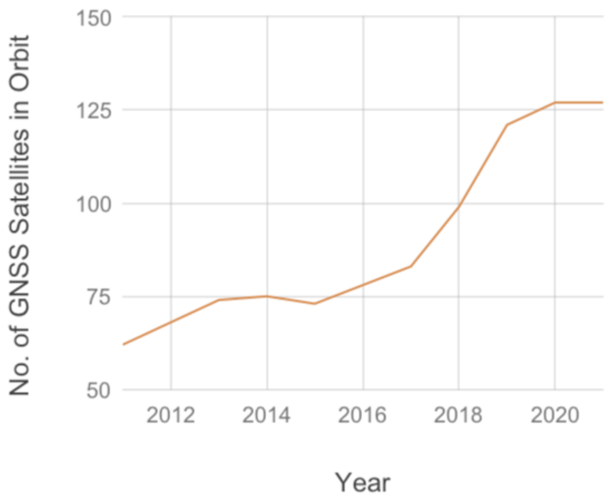
But Suffers from Limited Precision, Errors and Faults

Errors include Noise and Biases

Faults include outages, false transmissions, and spoofing

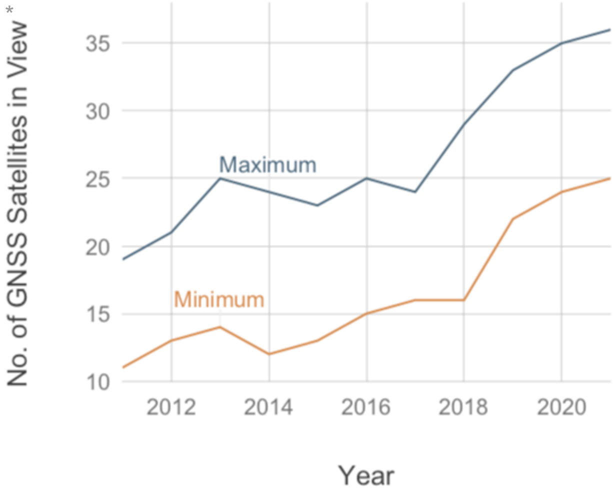
Developments in Modern High Precision GNSS

Multiple Independent GNSS Constellations



Four Global Constellations

GPS (USA)
GLONASS (Russia)
Galileo (EU)
BeiDou (China)



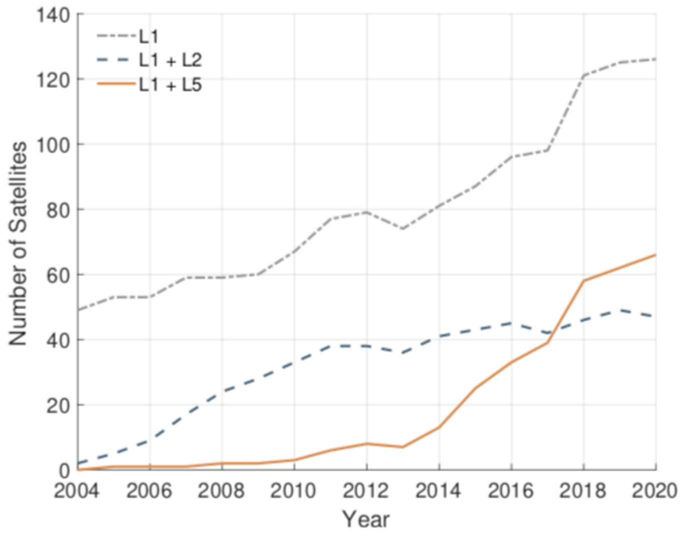
Provides Redundancy

7x over-provisioned increases availability

Quad independent constellation redundancy enables cross-checking and resiliency to individual constellation failures

* Over SF over 24 hours.

Modern Signals Across Multiple Frequencies



Band	Constellation and signal	Range resolution [m]	Carrier phase lock mean [sec]	Freq protection
L1	Glonass L1OF	600	2	good
L2	Glonass L2OF	600	2	poor
L1	GPS L1CA	300	6	good
L2	GPS L2C	300	0.1	decent
L1	Galileo E1BC	100	0.1	good
L1	Beidou3 B1C	100	0.1	good
L5	Galileo E6BC	60	0.1	bad
L5	Beidou3 B3I	30	6 (?)	bad
L5	GPS L5, Galileo E5a/b, Beidou3 B2a	30	0.1	good
L5	Galileo AltBOC, Beidou3 AltBOC	5	0.1	good

Triple-Frequency

L1, L2, L5 Frequency Bands

L5 is regulated by the ITU as a Safety-of-Life Service, providing legal protection against interference, channel sharing, spoofing and jamming.

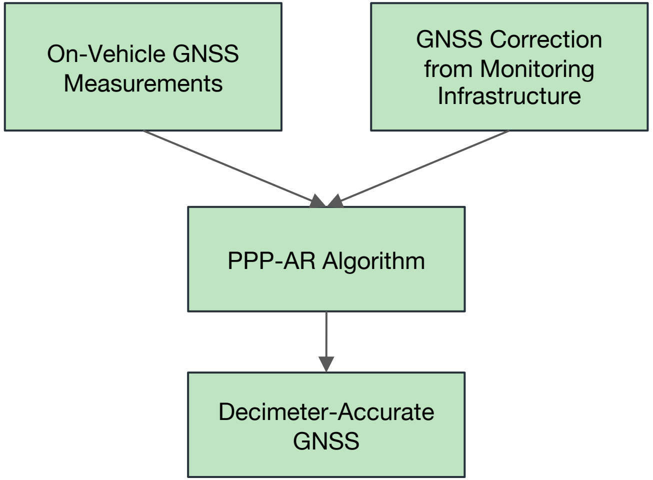
Modernized Signals

<100ms signal acquisition time
<10cm pseudorange noise

Provides Redundancy and Boosts Performance

Much improved performance on accuracy and convergence time. Protection against interference.

Algorithms to Correct Errors and Faults



PPP-AR

10cm (1σ)

Converges in Minutes

Continent-Scale Coverage

Modern Technique, Target for Automotive

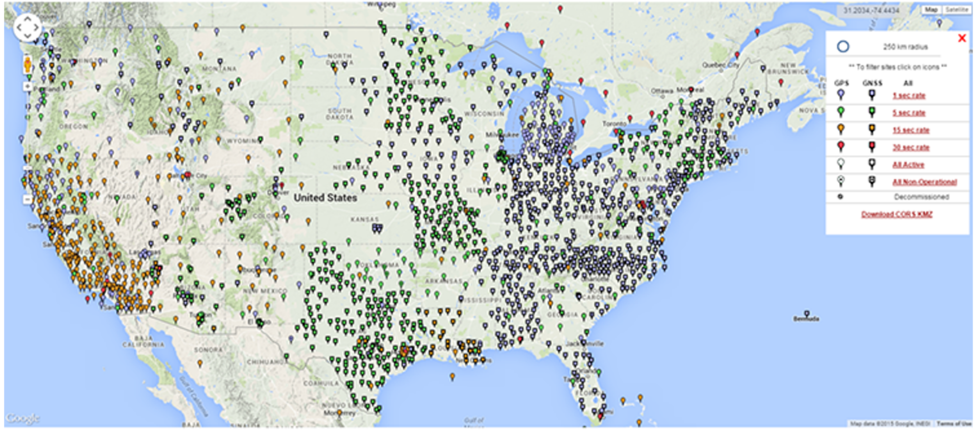
Injests Signals from GNSS Monitoring

Requires using fixed GNSS receivers that monitor the GNSS signal

Corrects Noise, Errors and Faults

Much improved performance on accuracy and convergence time. Protection against interference.

Ground-Based Monitoring Networks



Corrections Networks

Continent-wide ground station networks continuously monitors the GNSS signal and the local atmosphere

Estimates Errors and Faults

Ground stations can estimate errors and detect faults

- Ionosphere delays
- Troposphere delays
- Clock drift
- Orbital drift
- Hardware biases and delays

Enables Precision and Integrity

Provides corrections service to achieve continent-wide decimeter-level accuracy

Fault monitoring enables integrity outputs in the form of alerts that signal when GNSS cannot guarantee performance within bounds.

Data Standards For Corrections in 5G Rollout

5G Standardization for Interoperability

Corrections format containing error corrections (clocks, orbits, iono, tropo, etc…) and integrity information (fault status, etc)

Being integrated in the NR standard for 5G deployments.

Corrections is becoming a Utility

Corrections information is becoming part of the cell infrastructure delivered globally.

Carriers are providing corrections as a utility, interoperable between devices and suppliers.

High Precision and Integrity Outputs is becoming commercially available to automotive.

3GPP TS 36.171 V10.1.0 (2011-04)

Technical Specification

3rd Generation Partnership Project;
Technical Specification Group Radio Access Network;
Evolved Universal Terrestrial Radio Access (E-UTRA);
Requirements for Support of Assisted Global Navigation Satellite System (A-GNSS)
(Release 10)

The present document has been developed within the 3rd Generation Partnership Project (3GPP ™) and may be further elaborated for the purposes of 3GPP..
The present document has not been subject to any approval process by the 3GPP Organizational Partners and shall not be implemented.
This Specification is provided for future development work within 3GPP only. The Organizational Partners accept no liability for any use of this Specification.
Specifications and reports for implementation of the 3GPP ™ system should be obtained via the 3GPP Organizational Partners' Publications Offices.

Modern Geodetic Datums & Crustal Models

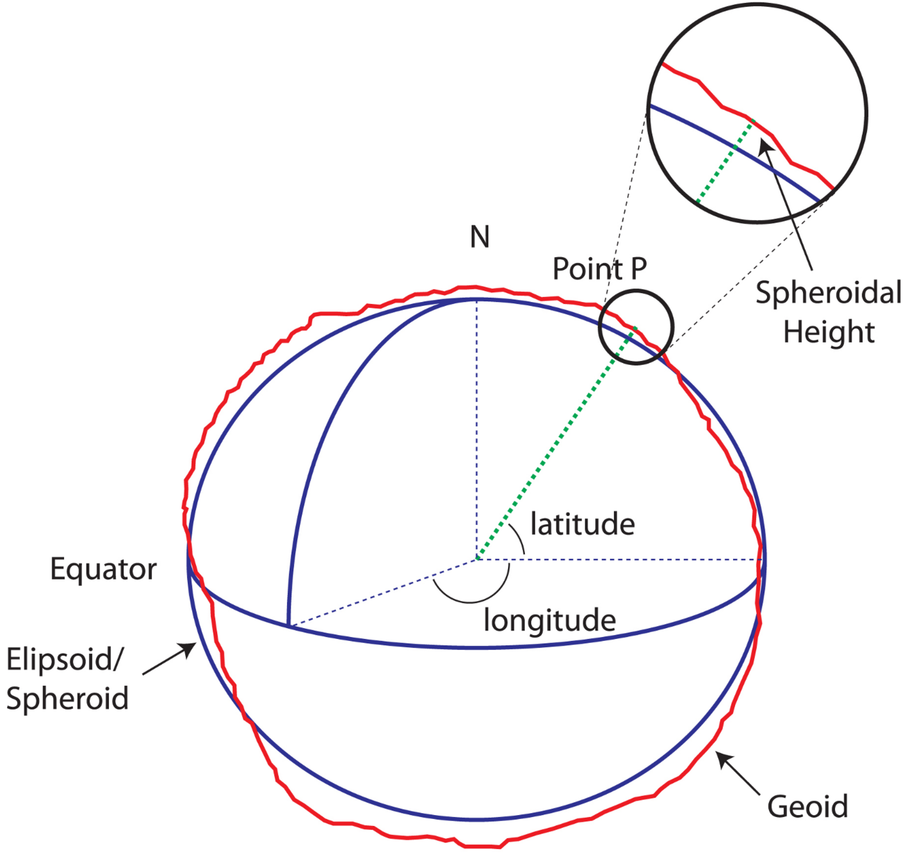
Accurate Reference Frame and Reference Ellipsoid

Some parts of California coastline moves ~10cm per year

New models (ITRF2014, NOAA's HTDP, etc.) takes into account dozens of variations in earth crustal activity and tracks crustal drift over time.

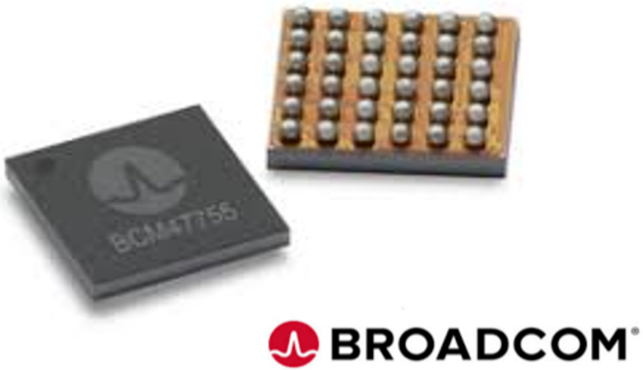
High Precision Maps can be Globally Localized

Features on High Precision Maps can be accurately localized on a global, absolute reference frame.

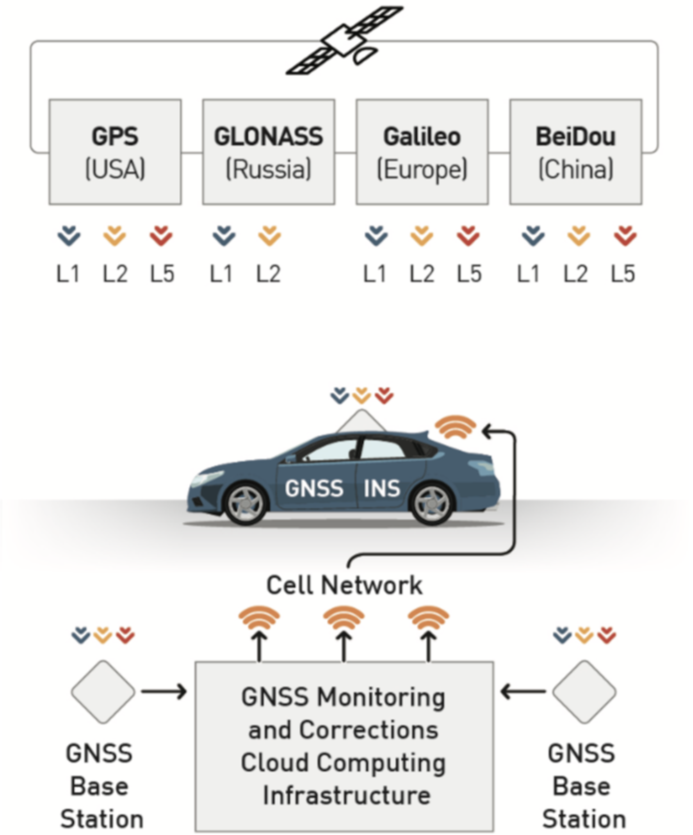


Mass-Market Automotive Chipsets

~$10 Automotive Grade Multi-Frequency Corrections-Ready GNSS Modules



Putting It All Together



Results

Steady March of Accuracy

Select Mass Market Automotive GNSS Performance since 2000

TABLE II

SELECT DATA POINTS THAT SHOW ON-ROAD GNSS PERFORMANCE IMPROVEMENTS BETWEEN 2002-2019.

Source	Year of Data	Data Set	Const.	Freq.	Receiver Type	GNSS Correc-tions	Env.	Accuracy	Availability	Outage Times
[50]	2000	2 hours	GPS	L1	Survey	None	Urban	10m, 74%, Lateral	28%	4.7 min, Worst-Case
[51]	2010	186 hours (13,000 km)	GPS	L1	Survey	None	Urban, Suburban, Rural, Highway	-	85%, Code Phase Position (HDOP $>$ 3)	28 sec, 95%, Code Phase Position (HDOP $>$ 3)
[47]	2017	1 hour	GPS, GLO, Gal	L1, L2	Mass Market	PPP-RTK	Suburban	0.77m, 95%, Horizontal	-	-
[52]	2018	355 hours (30,000 km)	GPS, GLO	L1, L2	Survey	Net. RTK	Mostly Highway	1.05m, 95%, Horizontal	50% Integer Ambiguity Fixed	10 sec, 50%, 40 sec, 80% Fixed
[53]	2019	2 hours	GPS, Gal	L1, L2	Research SDR	Net. RTK	Urban	0.14m, 95%, Horizontal	87% Integer Ambiguity Fixed	2 sec, 99%, Fixed
Swift Navigation	2019	12 hours (1,312 km)	GPS, Gal	L1, L2	Mid-Range	Proprietary, Continent-Scale	Mostly Highway	0.35m, 95%, Horizontal	95% CDGNSS	-

Step Change in Safety of Life

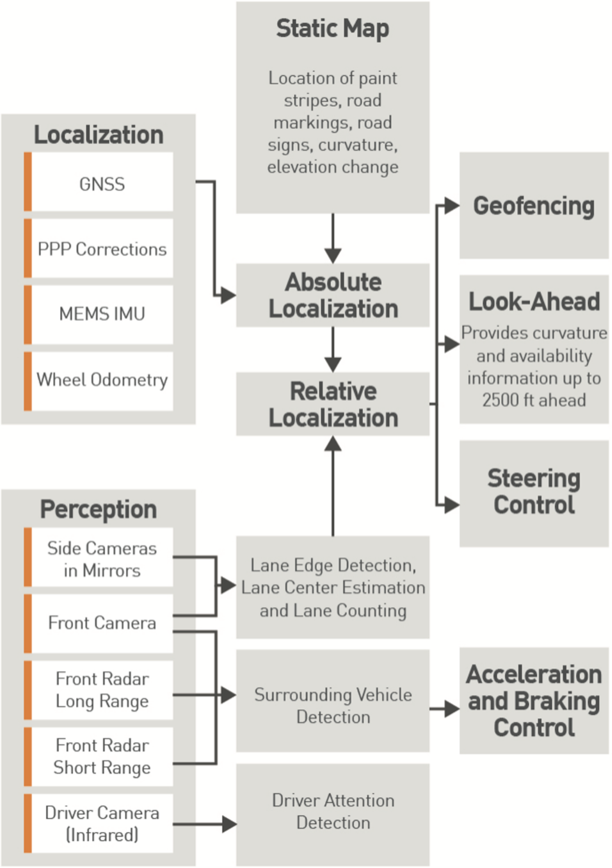
Integrity Outputs Enable Safety-of-Life guarantees

Provides Fault Alerts with very low probability of false negative for meter-scale faults.

Green Circle represents 1e-7 integrity guarantee [GMV MagicPPP]

Impact on Autonomy Architectures

SAE Level 2 Vision-based Systems

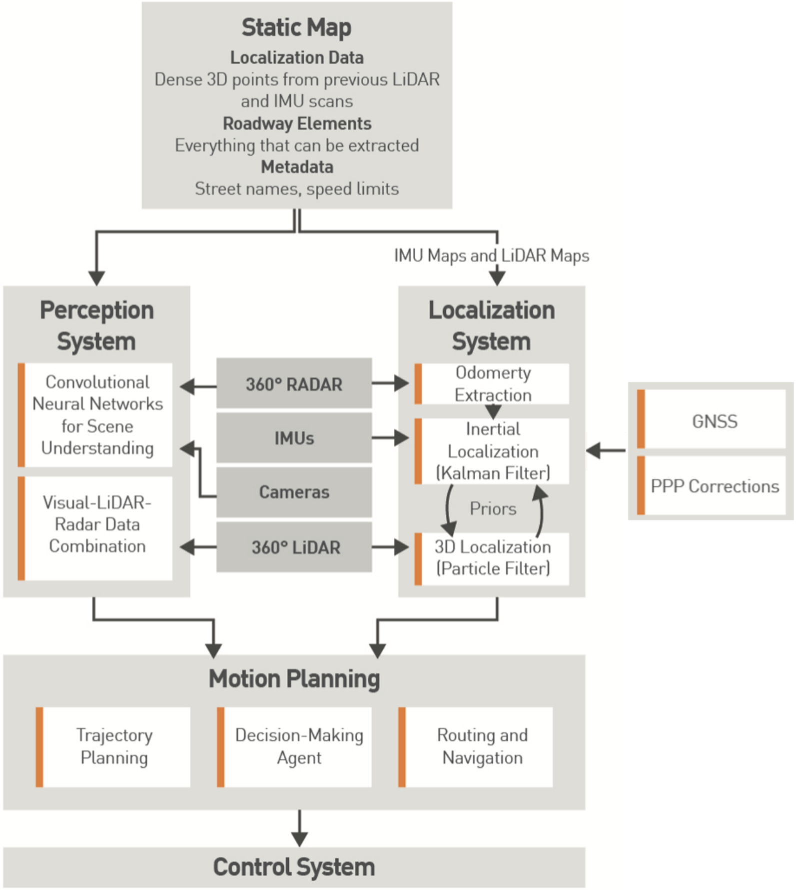


GNSS provides Lane Determination with High Certainty

Safe Lane-Level Maneuvers such as changing lanes into an exit lane.

Protection against dangerous vision errors such as false lane detections steering the car into highly hazardous areas.

SAE Level 4 LiDAR-based Systems



GNSS Complements LiDAR

LiDAR localization experiences errors and faults, often in environmental conditions where GNSS works particularly well, such as areas with little geometry (freeways!)

Provide Localization when LiDAR struggles such as on freeways

Provides Fallback during Outages such as degraded operation if LiDAR faults

Independence of GNSS drives localization safety case since the error modes of GNSS is not correlated to the error modes of perception sensors

Looking to the Future: Beyond One Vehicle

The GNSS Ecosystem Enables Vehicle to Vehicle and Vehicle to Infrastructure Collaboration to Overcome Occlusion, Share Perception, and Collaborate Between Vehicles and Manufacturers

Thank you!

More details in our paper!

“Developments in Modern GNSS and Its Impact on Autonomous Vehicle Architectures”

https://arxiv.org/abs/2002.00339

We’re happy to take questions by email!

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