Lane Level Positioning for Seamless Autonomous Driving Applications: Challenges and Strategies
適用自駕車應用的車道級定位技術： 挑戰與策略

Prof. Kai-Wei Chiang, PhD
Department of Geomatics, NCKU
kwchiang@mail.ncku.edu.tw

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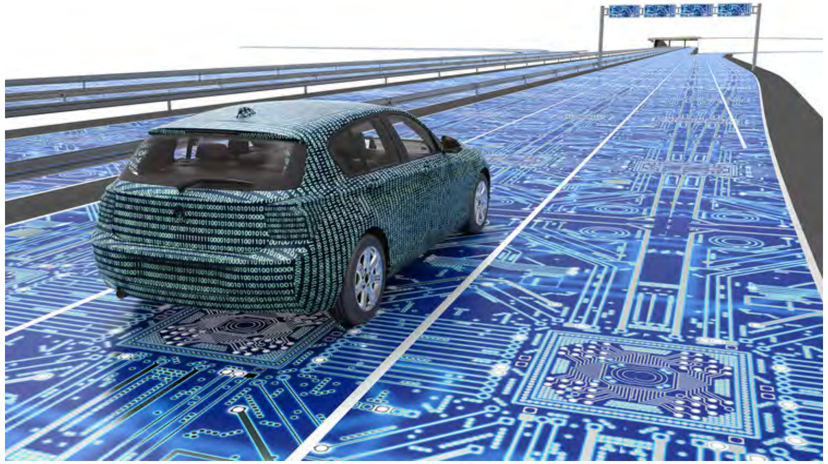
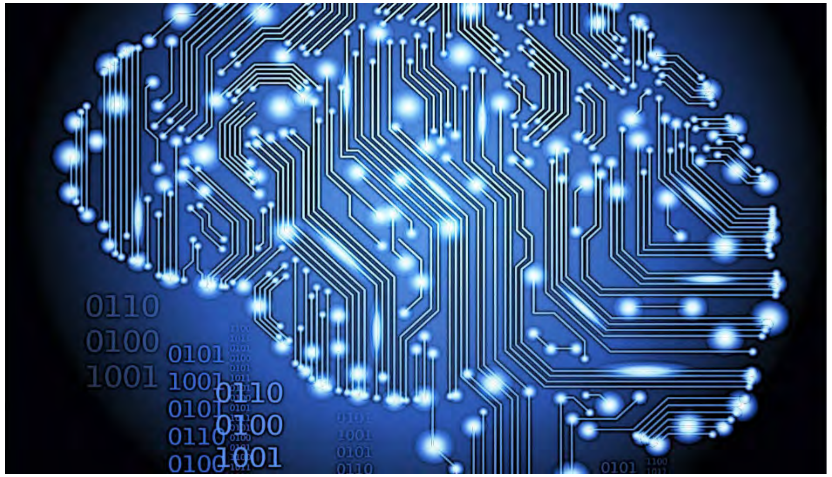
POINT

Outline

- Background
- Functional schemes of autonomous vehicles
- Lane level positioning : Challenges
- Lane level positioning : Strategies
- Future developments



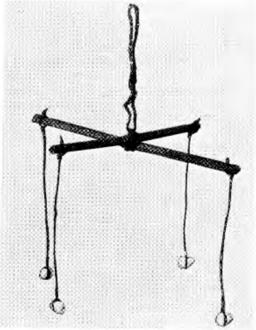
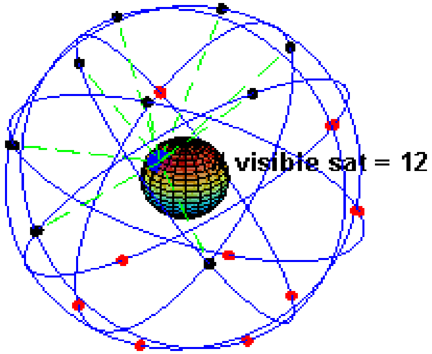


Background

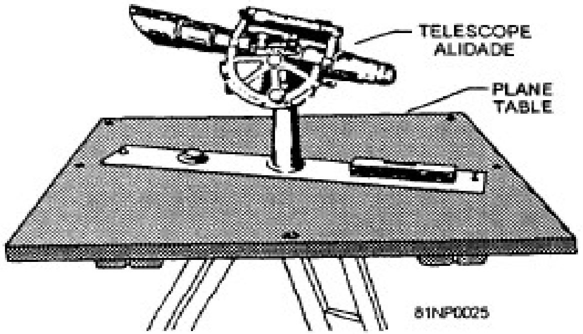
- Professional experiences

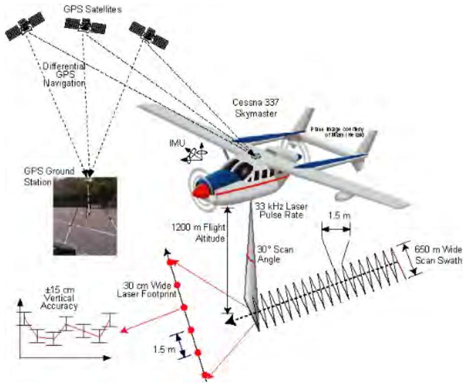
Background

- Evolution of positioning/sensing technologies

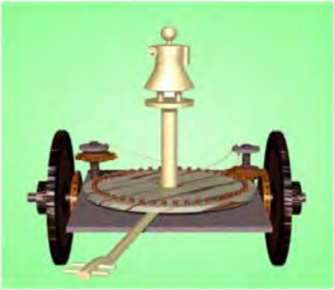




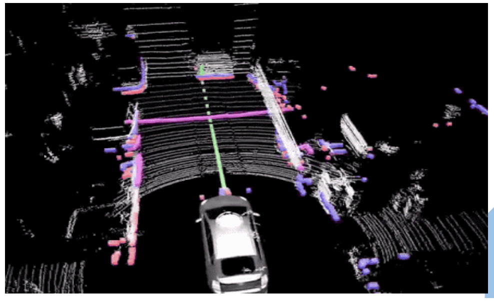












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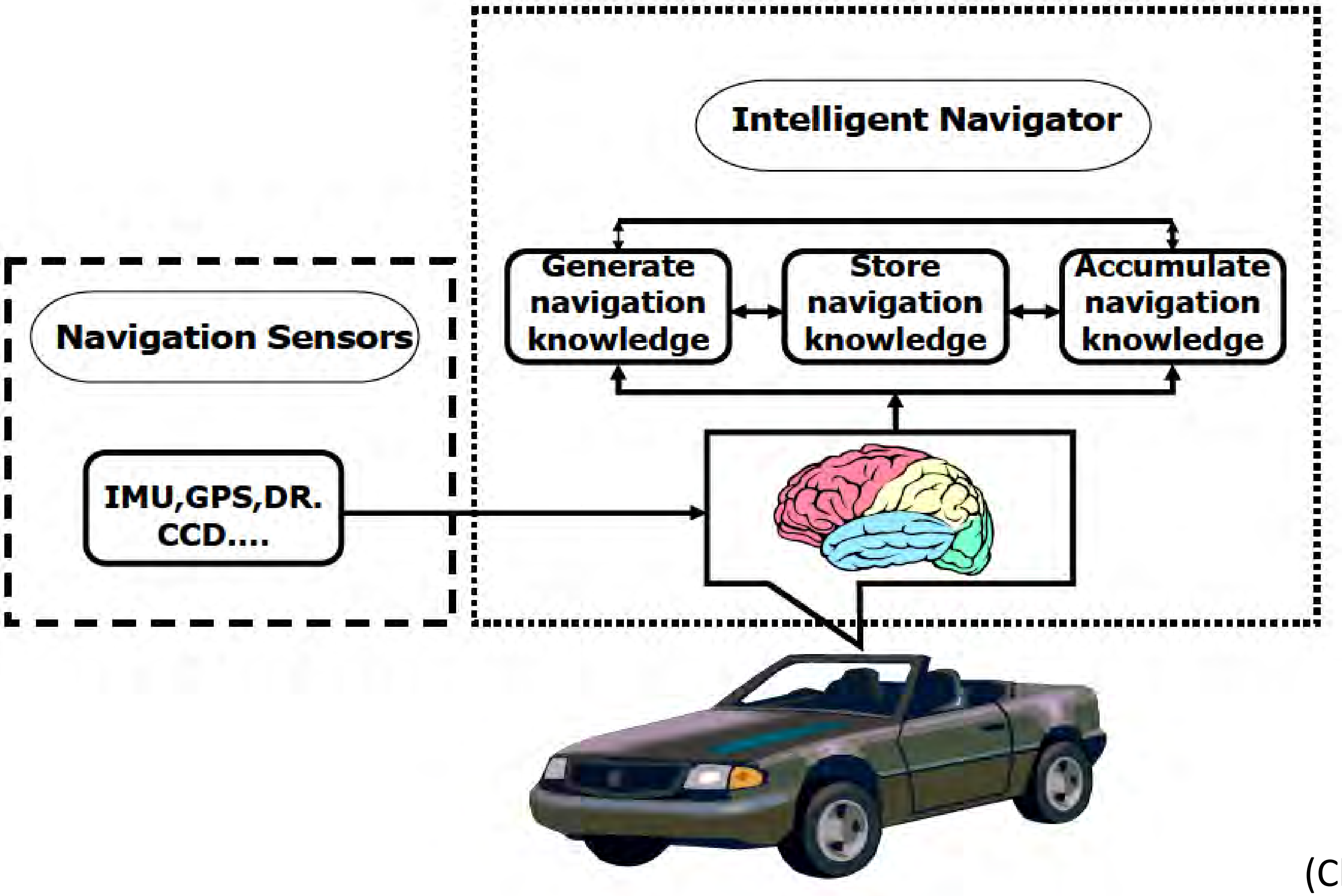
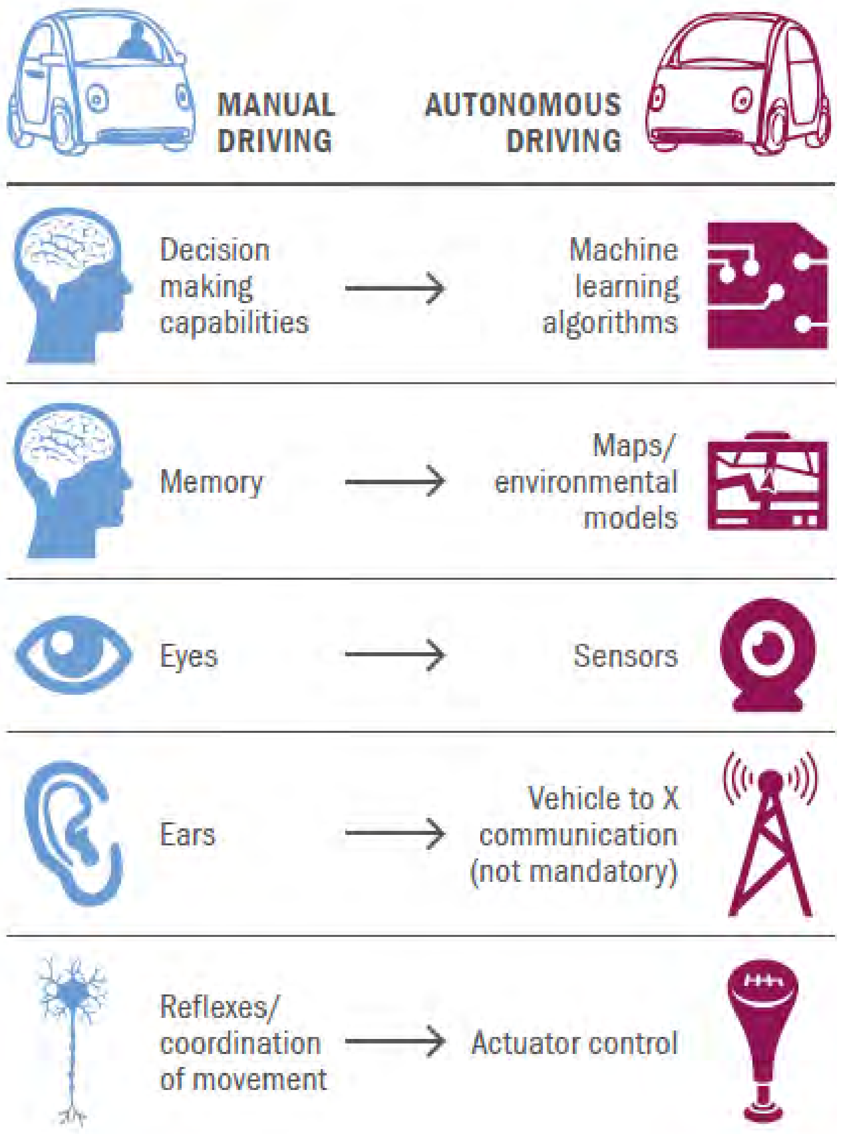


(Chiang et al., 2004)

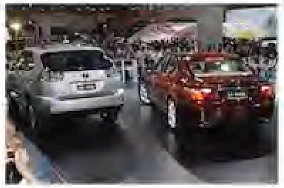
Background

- What’ s autonomous car
  - Capable of sensing its environment and navigating without human input
  - Technologies such as radar, LiDAR, GPS, IMU and camera vision help the vehicle feel their surroundings
  - Advanced control systems (algorithms) interpret sensory information to identify appropriate navigation paths, as well as obstacles and relevant signage



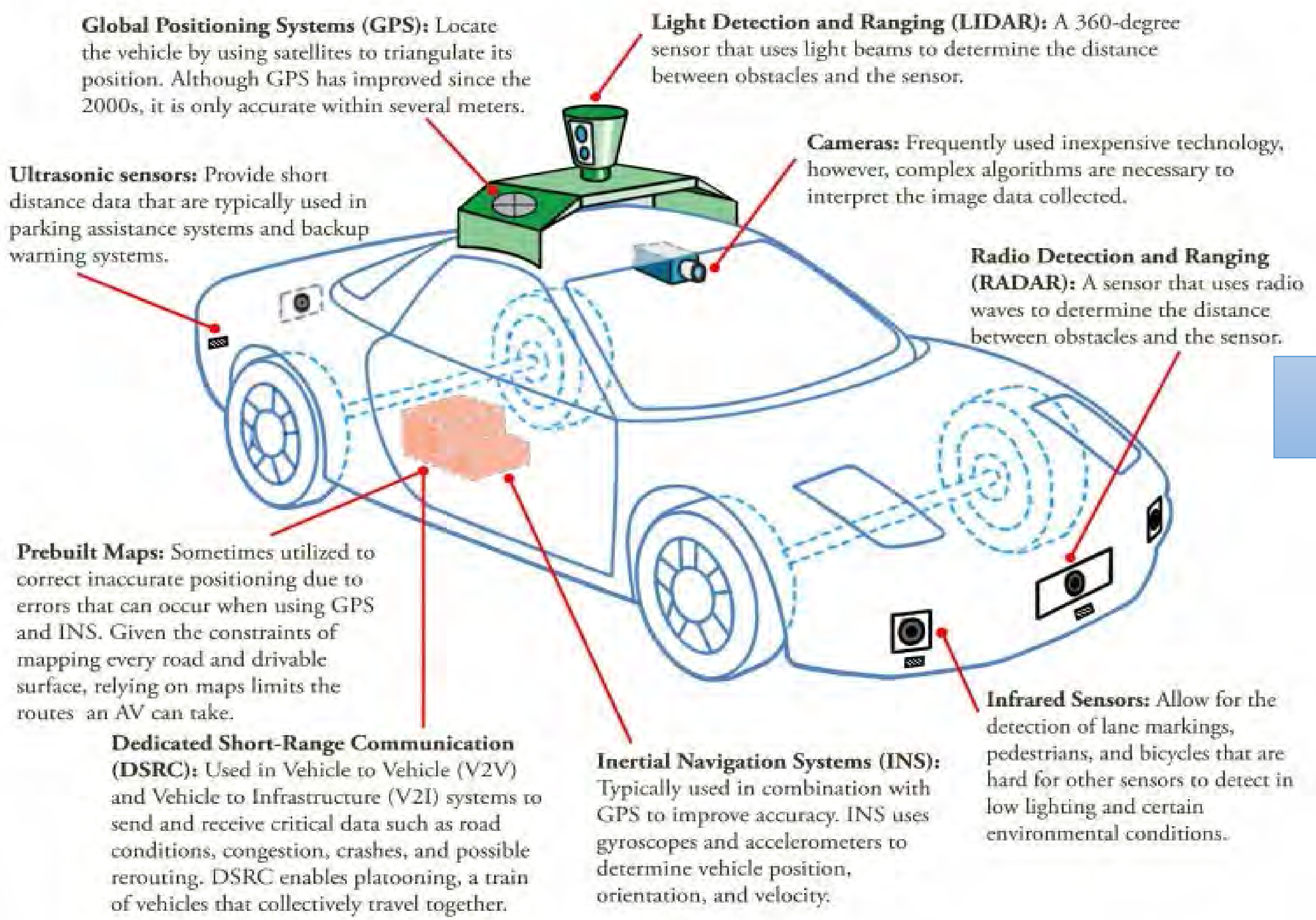
Background

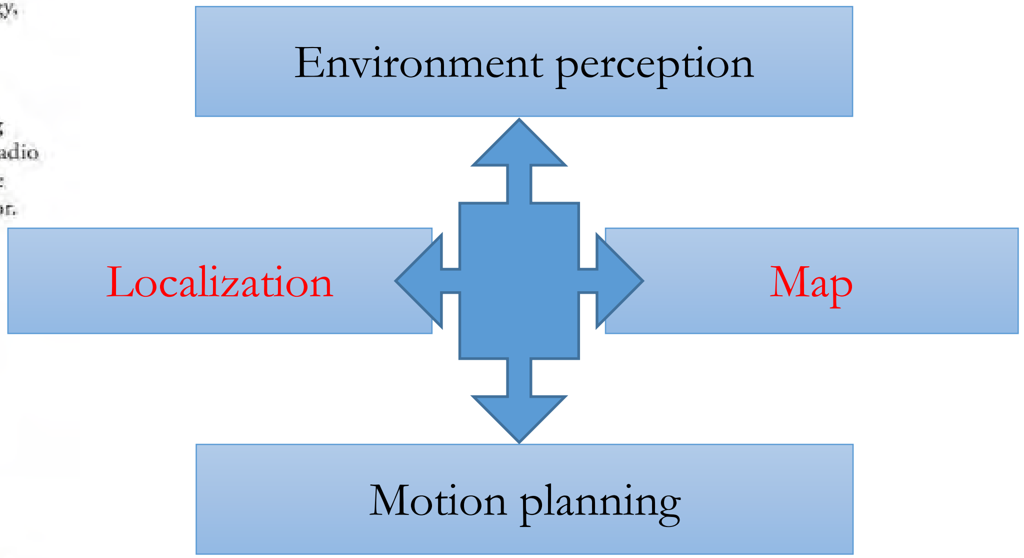
- Level of Autonomy

LEVEL 5 Fleets	No steering wheel All conditions		***Powerful*** lidar and radar, advanced computer vision, detailed maps, V2V, teleoperations
LEVEL 4 Fleets	No steering wheel Limited geographies and conditions		
LEVEL 3 Remote Ops & Drivers	Automated driving Occasional driver takeover $TRILLION OPPORTUNITY	MILLIONS OF CARS 	*Cheap* lidar and radar, computer vision
LEVEL 2 Drivers	Automated driving Constant driver oversight		*Cheap* radar, computer vision
LEVEL 1 Drivers	Driver assistance		Wheelspeed sensors, intertial sensors, cameras
LEVEL 0 Drivers	No automation		Headlights, taillights, windshield wipers

Functional schemes of autonomous vehicles

- Components of autonomous vehicles





Functional schemes of autonomous vehicles

- Environment sensing elements of autonomous vehicles

No sensor type works well for all tasks and in all conditions, so sensor fusion will be necessary to provide redundancy for autonomous functions

Most likely used fusion solution in future | Good | Fair | Poor

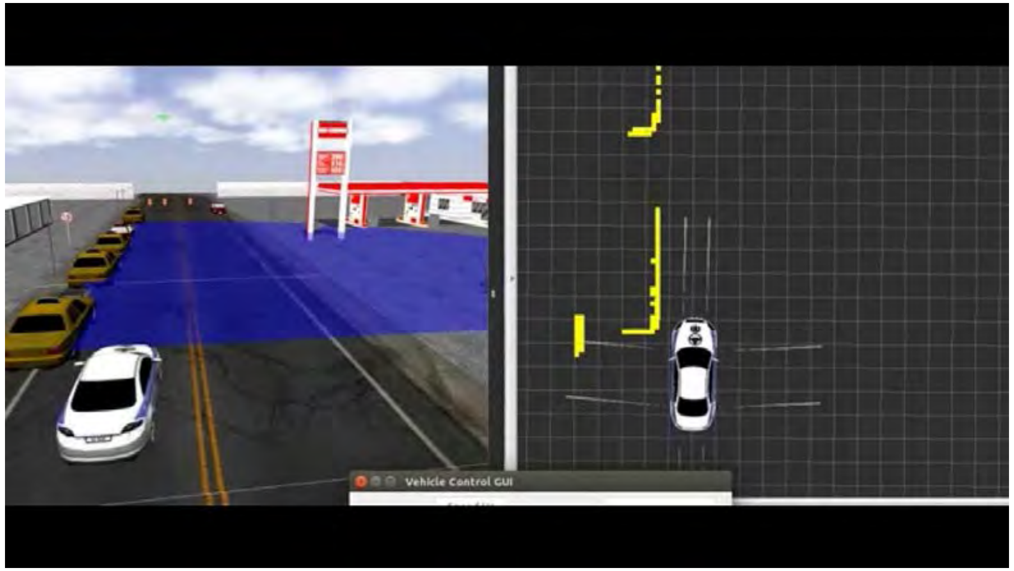
	Camera	Radar	LiDAR	Ultrasonic	LiDAR+Radar+ Camera
Object detection	Fair	Good	Good	Good	Good
Object classification	Good	Poor	Fair	Poor	Good
Distance estimation	Fair	Good	Good	Good	Good
Object edge precision	Good	Poor	Good	Good	Good
Lane tracking	Good	Poor	Poor	Poor	Good
Range of visibility	Fair	Good	Fair	Poor	Good
Functionality in bad weather	Poor	Good	Fair	Good	Good
Functionality in poor lighting	Fair	Good	Good	Good	Good

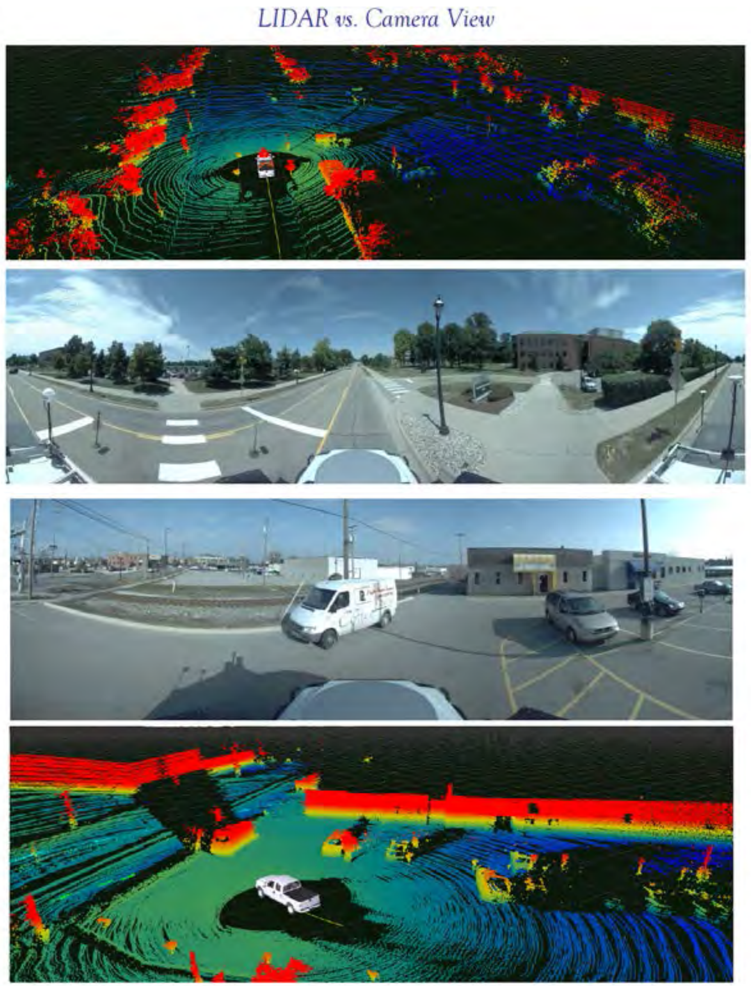
"Sensor fusion is key because the more complex features get, the more redundancy you need. Every autonomous vehicle is going to have some combination of LiDAR, Radar and camera."
– ADAS engineer at a prominent OEM

(Woodside,2016)

Functional schemes of autonomous vehicles

- Environment perception and localization

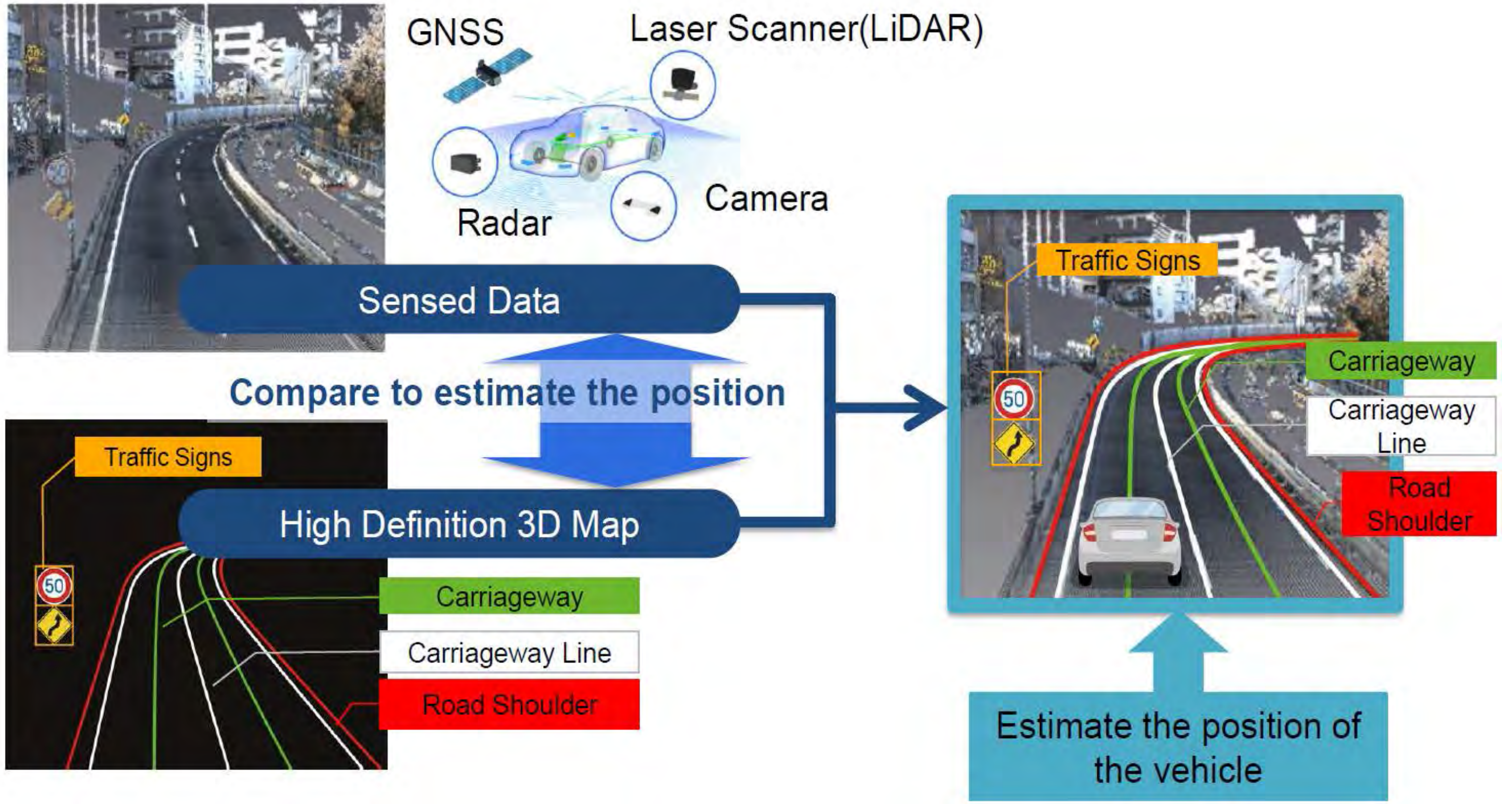




From: TomTom & Perceptual Robotics Lab at the University of Michigan

Functional schemes of autonomous vehicles

- How to use GNSS/IMU/ODO/LiDAR/camera and maps in navigating autonomous vehicles ?
  - Deploy MMS to generate 3D high definition base maps Offline
  - Map Matching Geo-referenced LiDAR point clouds and images produced in field with existing 3D base maps

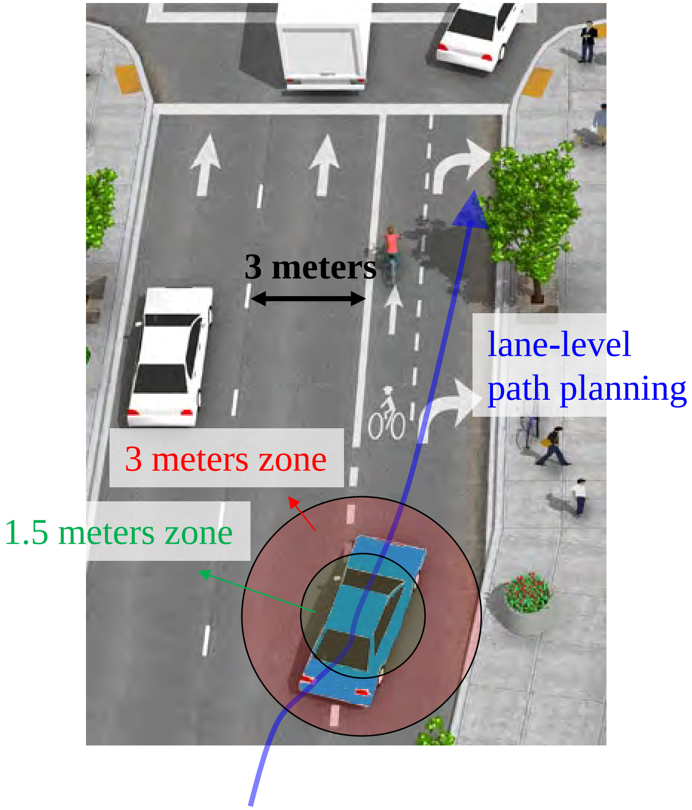


(SIP-Adus,2017)

Lane Level Positioning : Challenges

- Lane level positioning accuracy requirements

  - Real road tests by
    Daimler
    KIT
    Mercedes-Benz

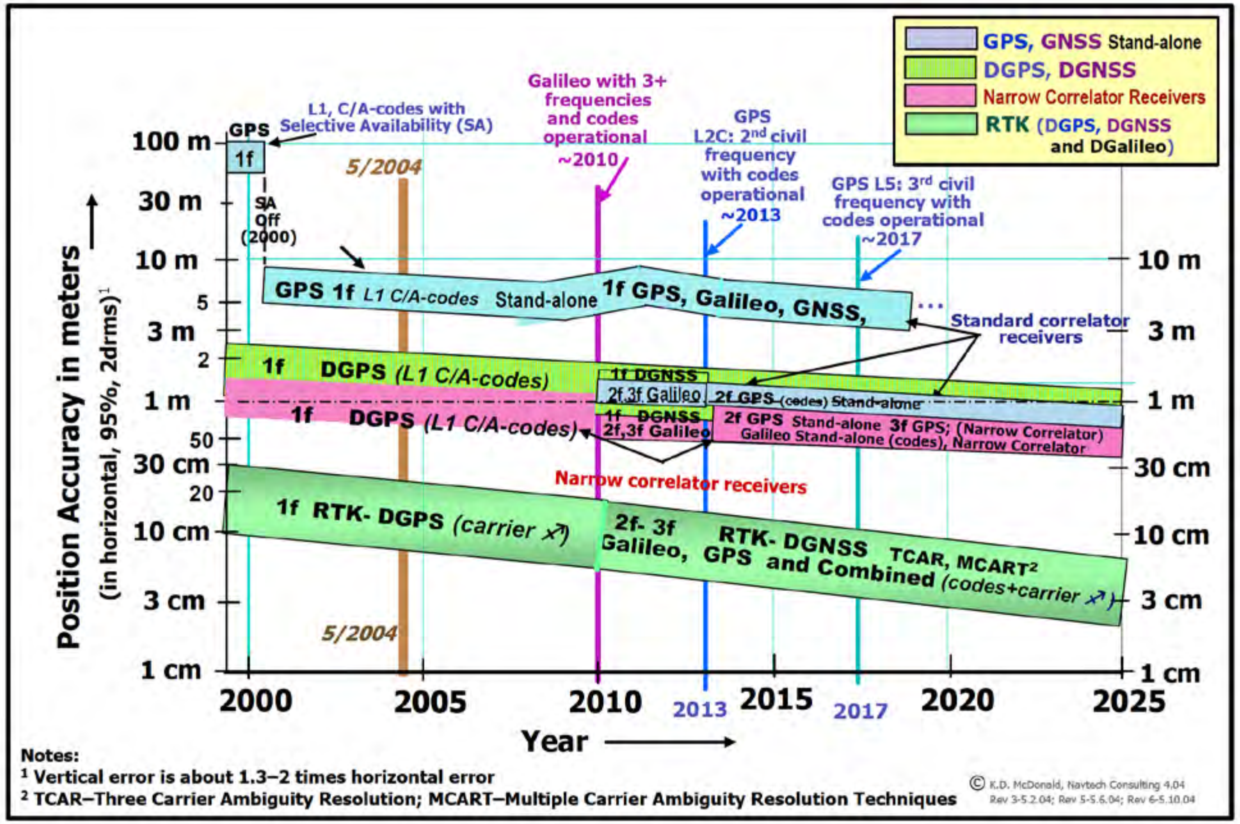


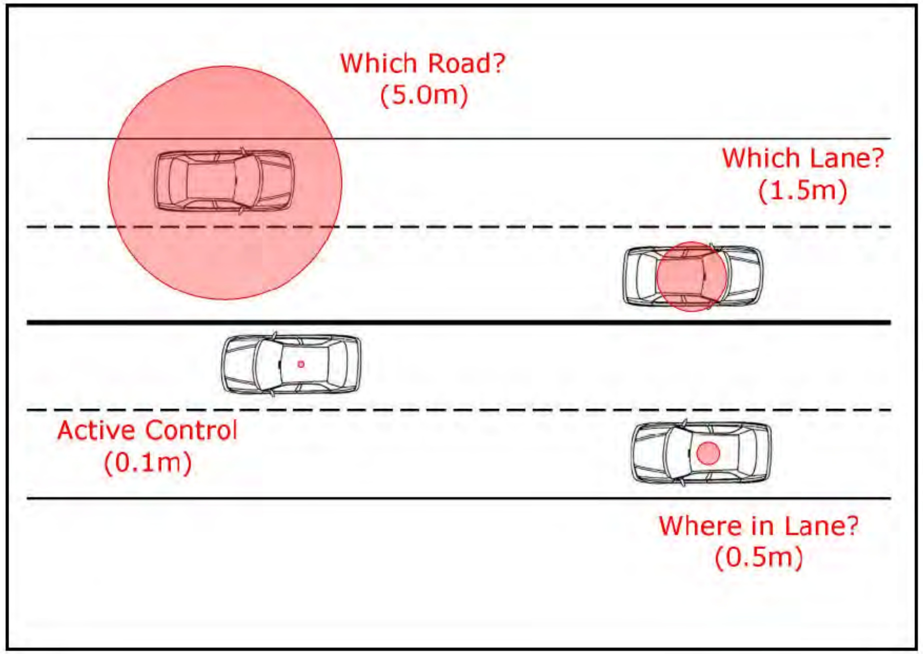
Daimler R&D Teams for Autonomous driving:

The technical requirements for identifying a vehicle's location are extremely difficult because the GPS navigation systems, currently do not provide sufficiently accurate data especially in city downtown.

Lane Level Positioning : Challenges

- Lane level positioning accuracy requirements



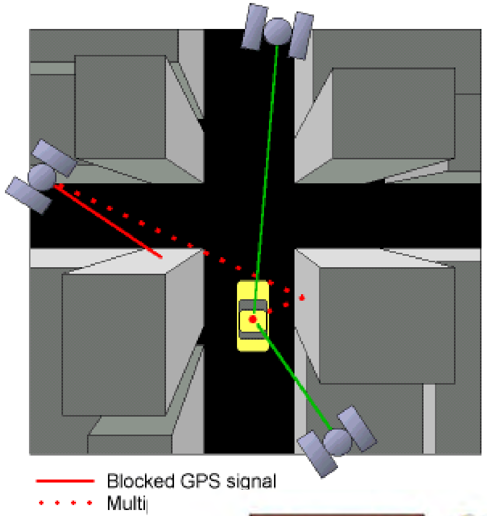


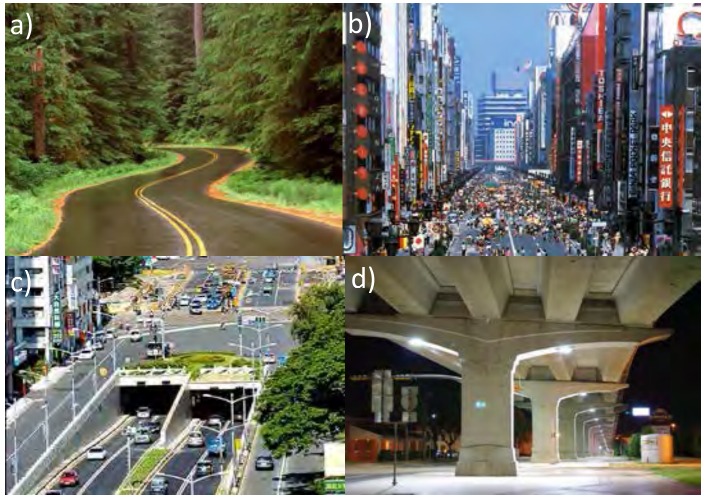
	Total Error Budget (map + vehicle) [meters 2sigma]	Map Error [meters 2sigma]	Vehicle Positioning Error [meters 2sigma]
WHICHLANE	1.5	0.5	1.0
WHEREINLANE	0.5	0.2	0.3

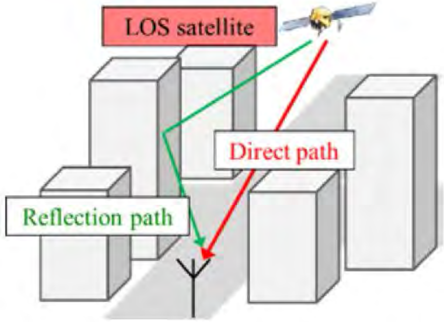
(CAMP, 2004)

Lane Level Positioning : Challenges

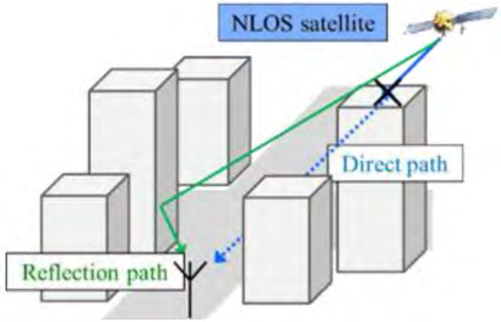
- GNSS in difficult environments
  - It matters for both navigation and mapping scenarios







(a) Multipath effect

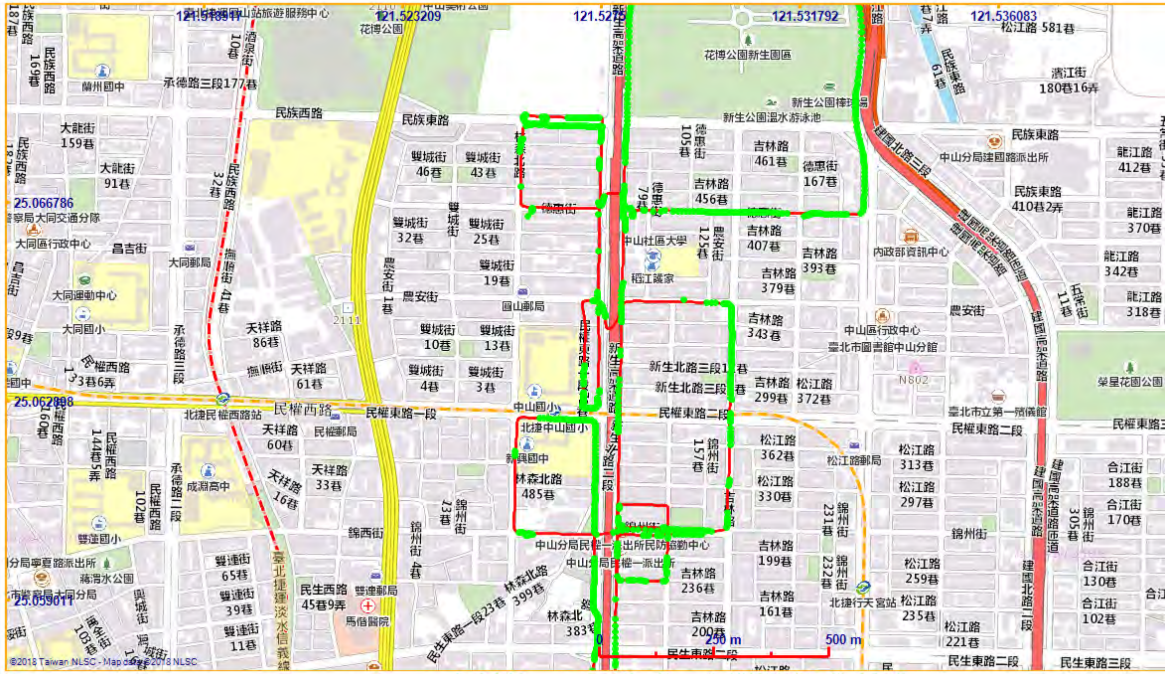


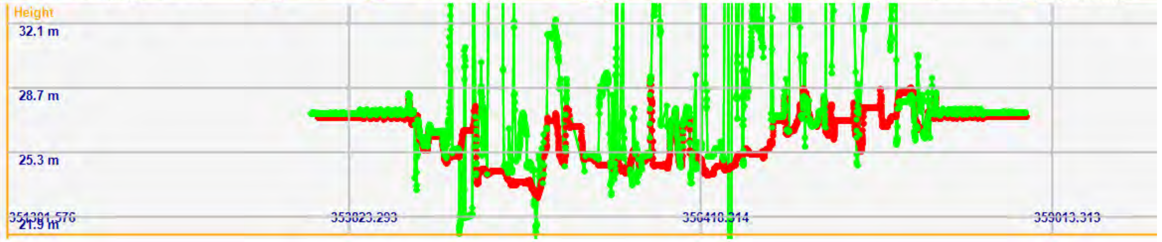
(b) NLOS effect

Lane Level Positioning : Challenges

- GNSS in difficult environments
  - It matters for both navigation and mapping scenarios

- Red – INS/GNSS
  - NovAtel Inc. SPAN-LCI
- Green – GNSS
  - NovAtel Inc. Propak 6



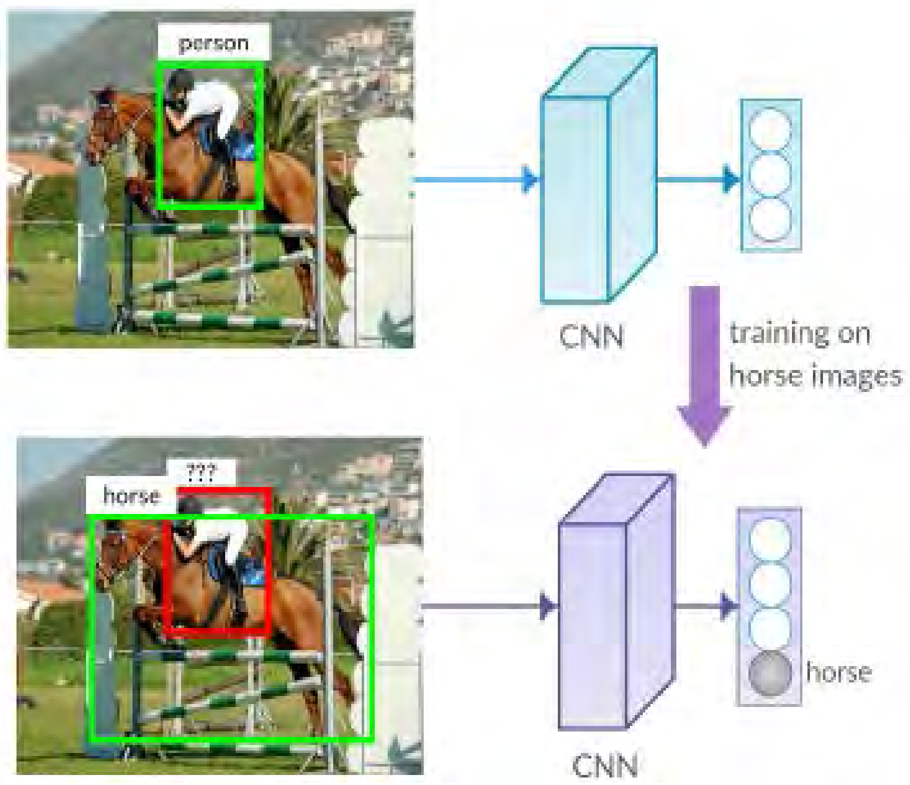


Lane Level Positioning : Challenges

- Limiting factors of AI
  - Training a deep network is computationally hard, and
    - Deep learning is useful only when it is combined with smart modeling/engineering
    - Domain knowledge is very helpful
    - only works for similar problems
    - Standard training algorithms are not always satisfactory for automotive applications
  - Computing power requirements and costs
  - Black box and lack of interpretation
    - understanding when and why it works is a great scientific mystery
  - Robustness of AI:
    - Most current AI systems can be easily fooled, which is a problem that affects almost all machine learning techniques.

Lane Level Positioning : Challenges

- Limiting factors of AI
  - Large datasets and hard generalization
    - Database size and training data arrangement
    - Re-training issues and catastrophic forgetting



Catastrophic forgetting.

- An object detector network originally trained for three classes, including person, detects the rider(top).
- When the network is retrained with images of the new class horse, it detects the horse in the test image, but fails to localize the rider (bottom).

Lane Level Positioning : Strategies

- Multi-sensor Fusion schemes

Camera

Identify road markings & traffics signs, keep the car within the lanes.

GPS

Absolute positioning information.

Connectivity

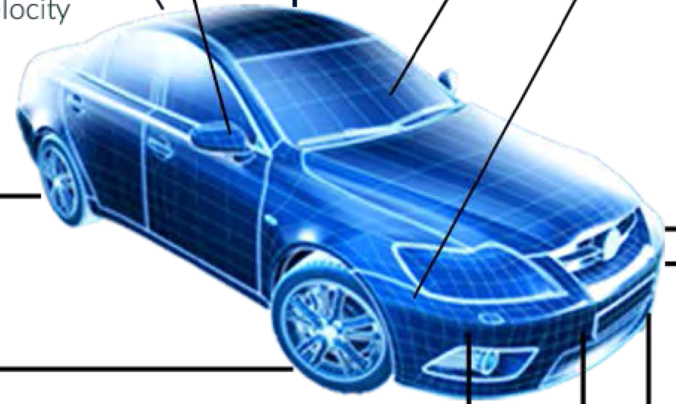
V2X & Digital Map Data.

IMU & Wheel Sensor

Provide acceleration, velocity & distance travelled.

Ultrasonic

Short distance objects.

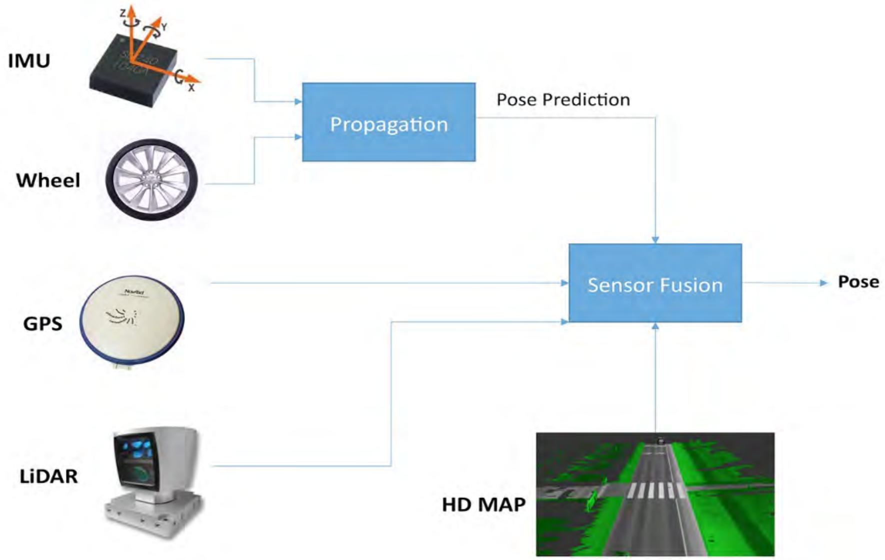


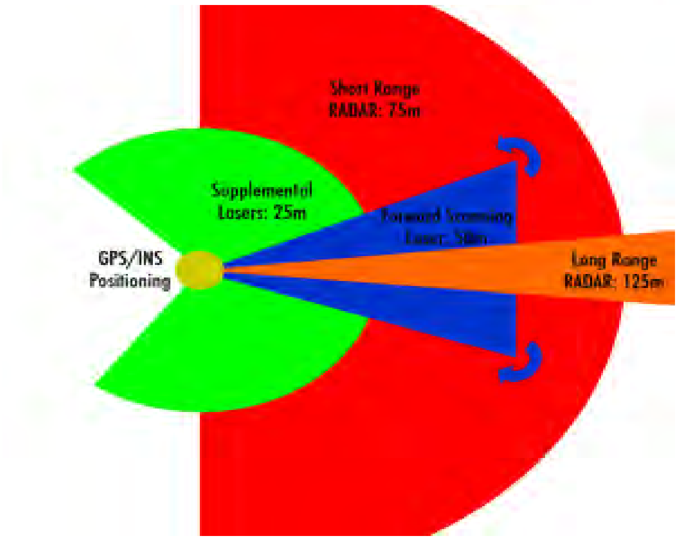
Radar

Judge distances & detect potential issues.

Lidar:

Multiple lasers help the car build a complete view of its surroundings.





Lane Level Positioning : Strategies

- Strategies to improve the performance of integrated systems in urban canyon
  - Hardware perspective
    - Using aiding sensors to provide physical constrains or actual movements of the vehicles
    - Requires new design of sensor fusion schemes to adopt new sensors
    - Odometer, barometer, camera, LIDAR, radar, HD maps
  - Software perspective
    - Using motion constrains or approximated motion models
    - New sensor fusion algorithms
      - Adaptive filter
      - Sampling filter
      - Artificial intelligence
      - to name a few

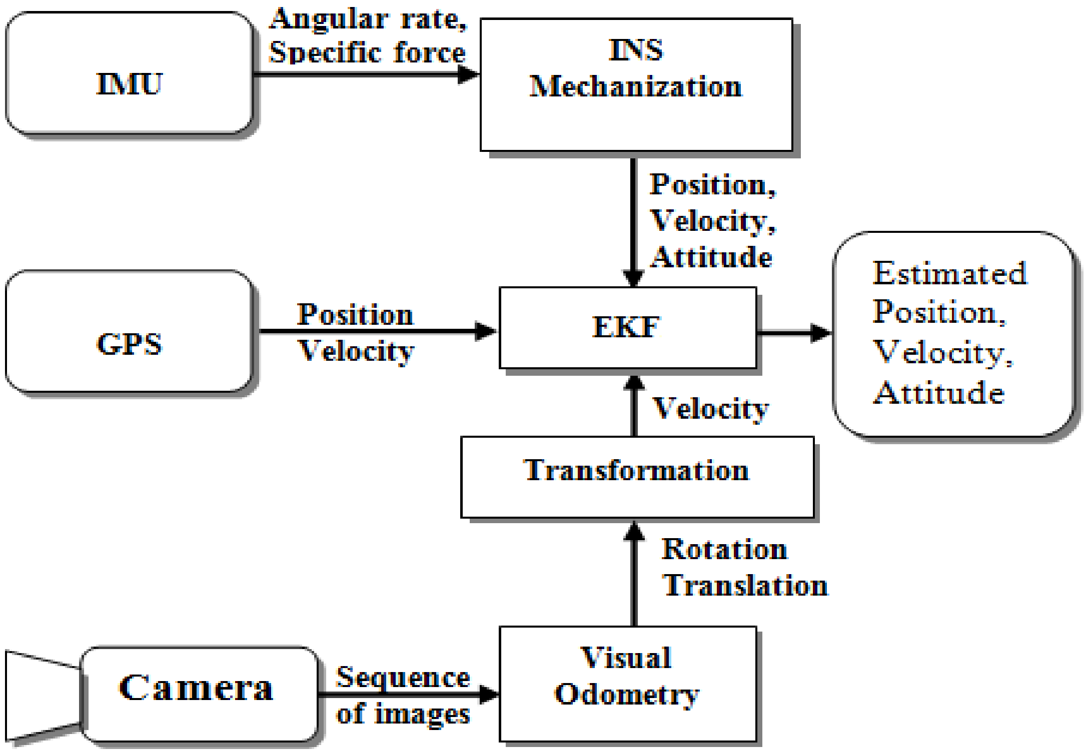
Lane Level Positioning : Strategies

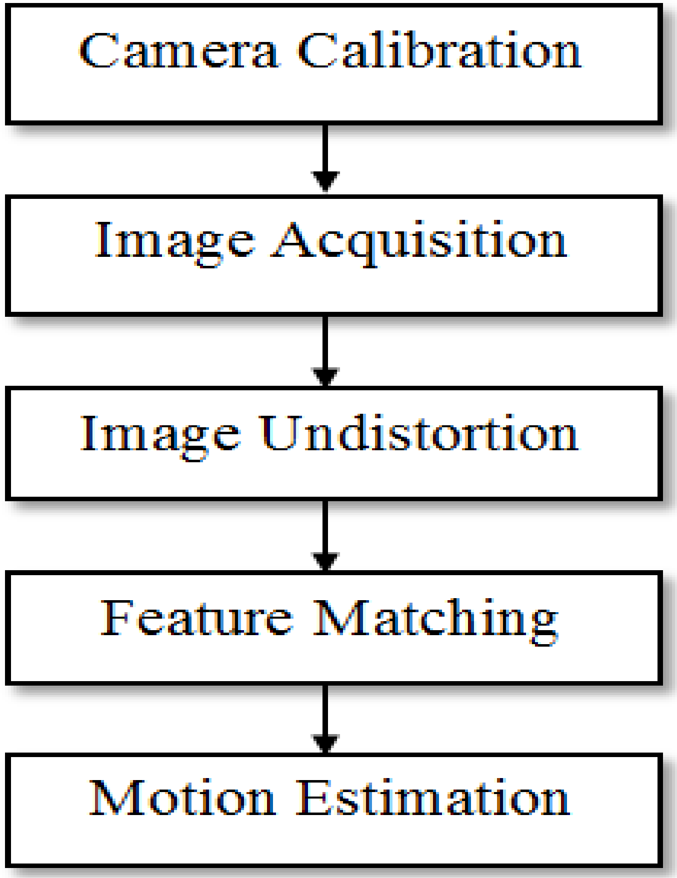
- Strategies to improve the performance of integrated systems in urban canyon

	Advantages	Disadvantages
Hardware perspective	• Simple filter design • Fast computation • Actual measurements from dynamic condition • General cases • Effective • Accurate	• Sensor synchronization • Sensor measurements acquisition and storage • Boresight and lever arm calibration between sensors • Sensor calibration • Cost
Software perspective	• Less sensor synchronization • Simple hardware design • Cost • Less calibration tasks	• Massive filter structure and complex filter algorithm • Slow • Learning task might apply • Case dependent

Lane Level Positioning : Strategies

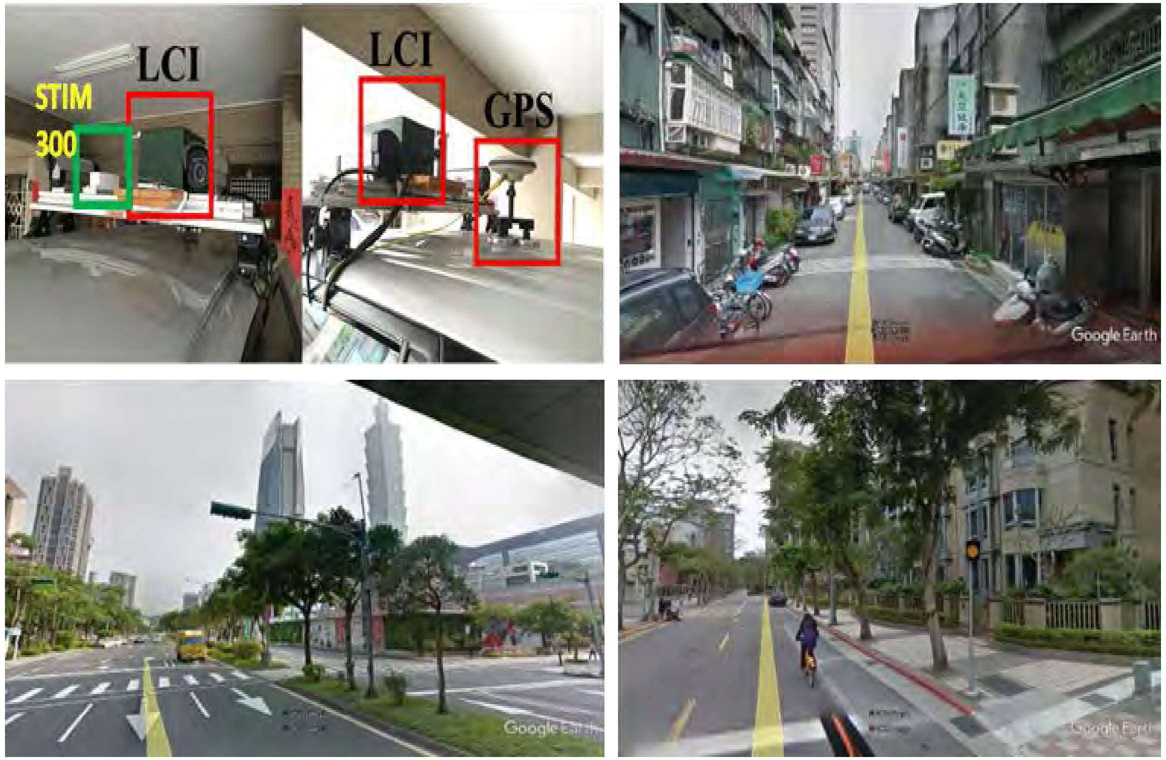
- GNSS/IMU/Camera

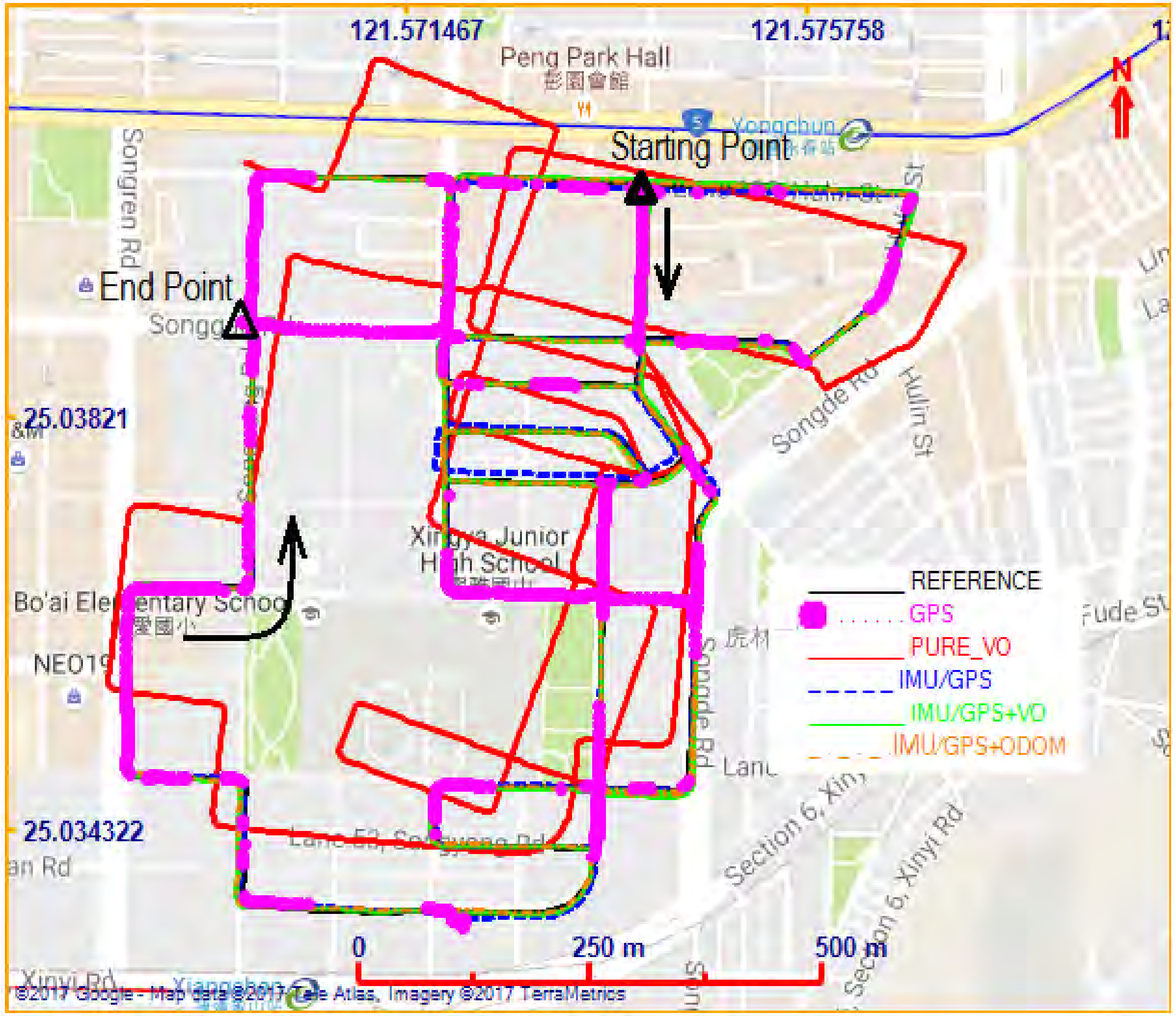




Lane Level Positioning : Strategies

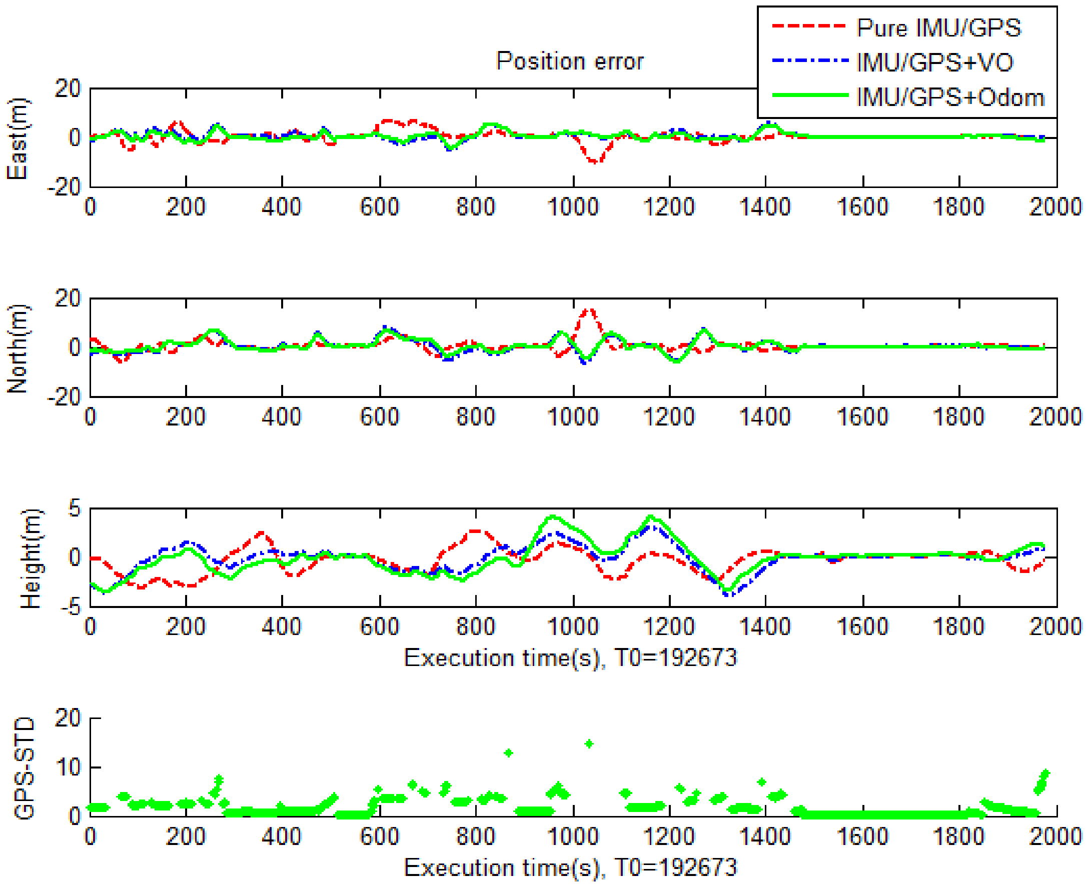
- Test-1

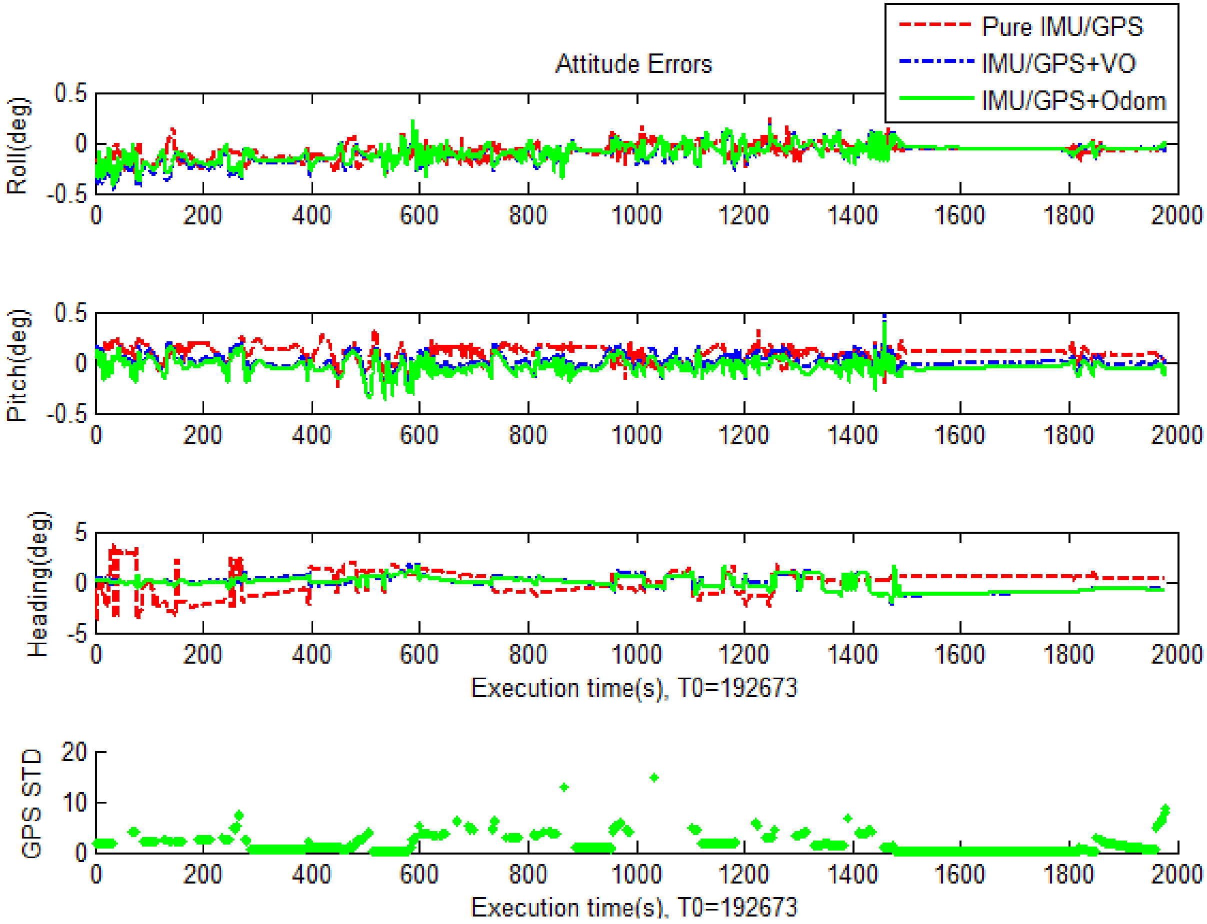




Lane Level Positioning : Strategies

- Test-1





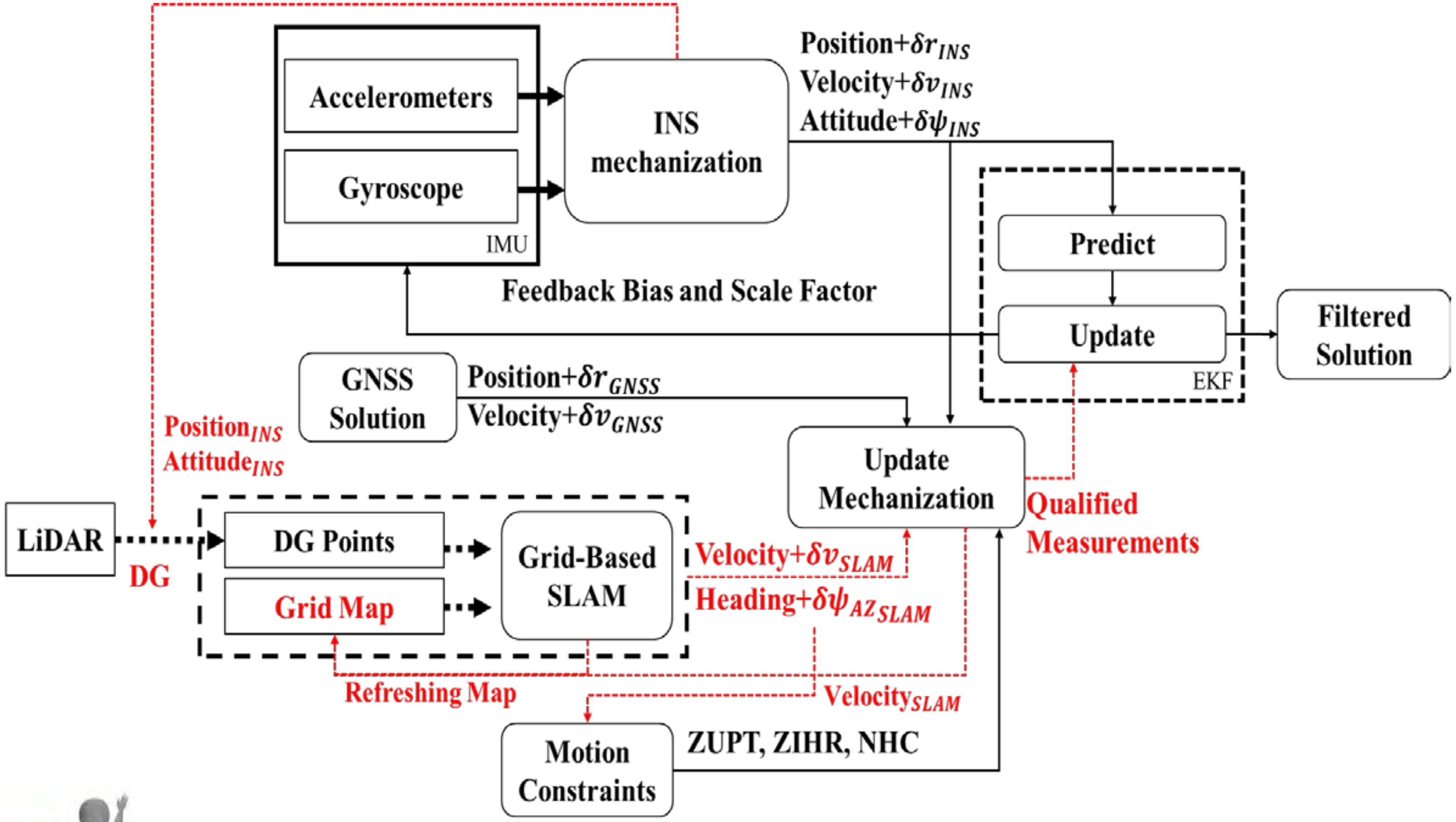
Lane Level Positioning : Strategies

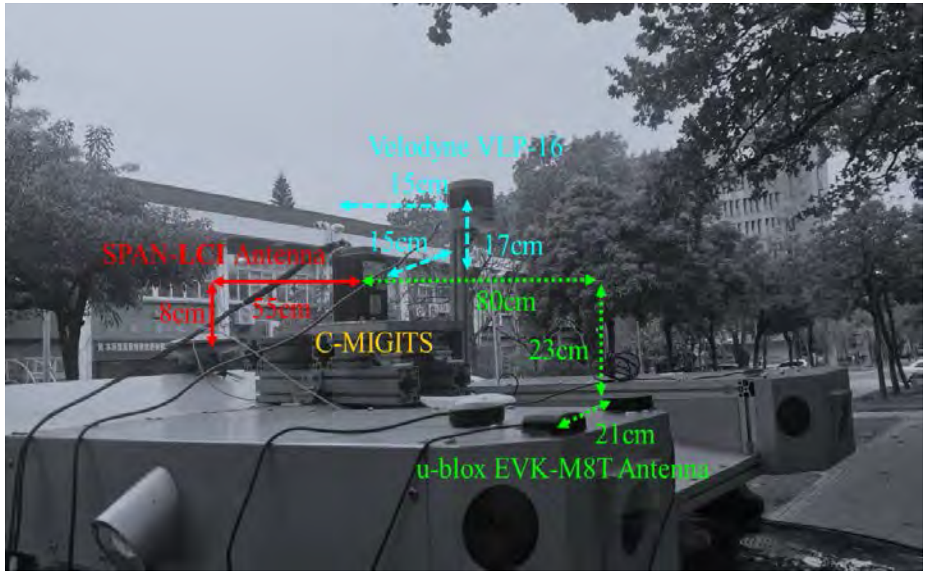
- Test-1

RMSE	IMU/GPS	IMU/GPS+VO	IMU/GPS+ODOM
Position			
East (m)	2.377	1.351	1.468
North (m)	2.503	1.212	1.361
Up (m)	1.558	1.224	1.561
3D (m)	3.787	2.190	2.518
Attitude			
Roll (o)	0.112	0.143	0.127
Pitch (o)	0.115	0.076	0.081
Heading (o)	1.172	0.428	0.699

Lane Level Positioning : Strategies

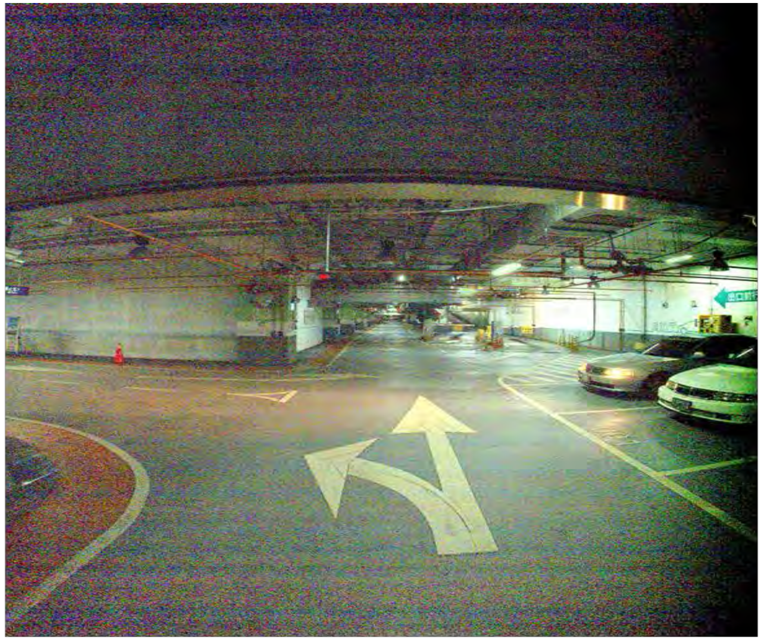
- GNSS/IMU/Lidar

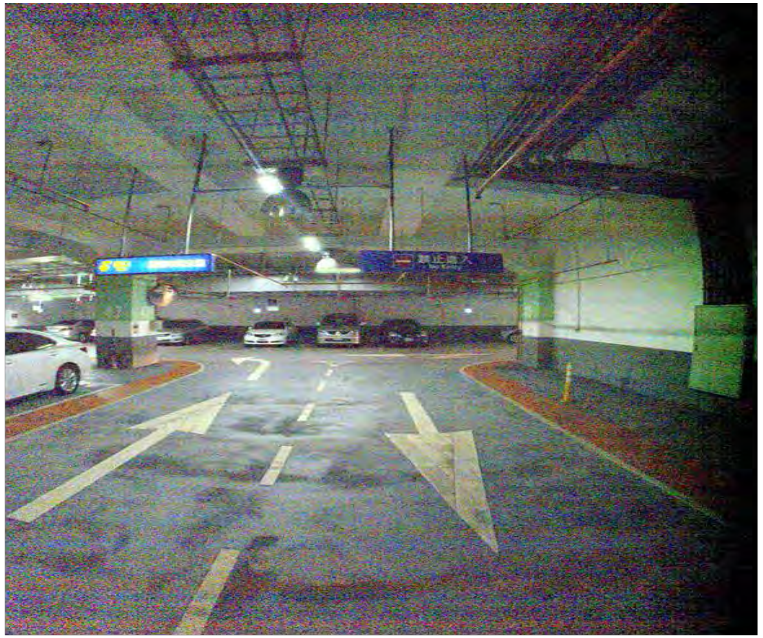


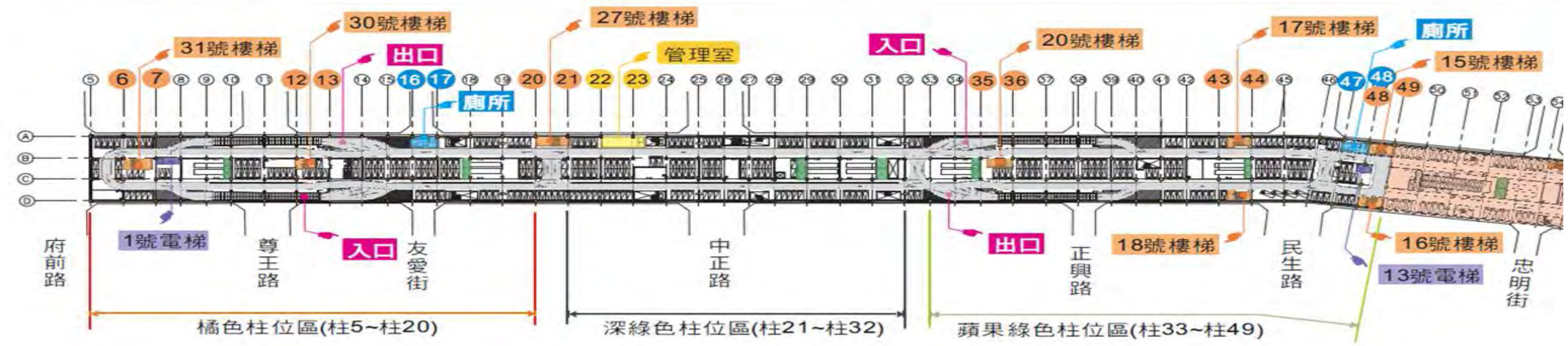


Lane Level Positioning : Strategies

- Test-2
  - Indoor
  - Travel distance> 1.5km
  - GNSS outages >7 minutes

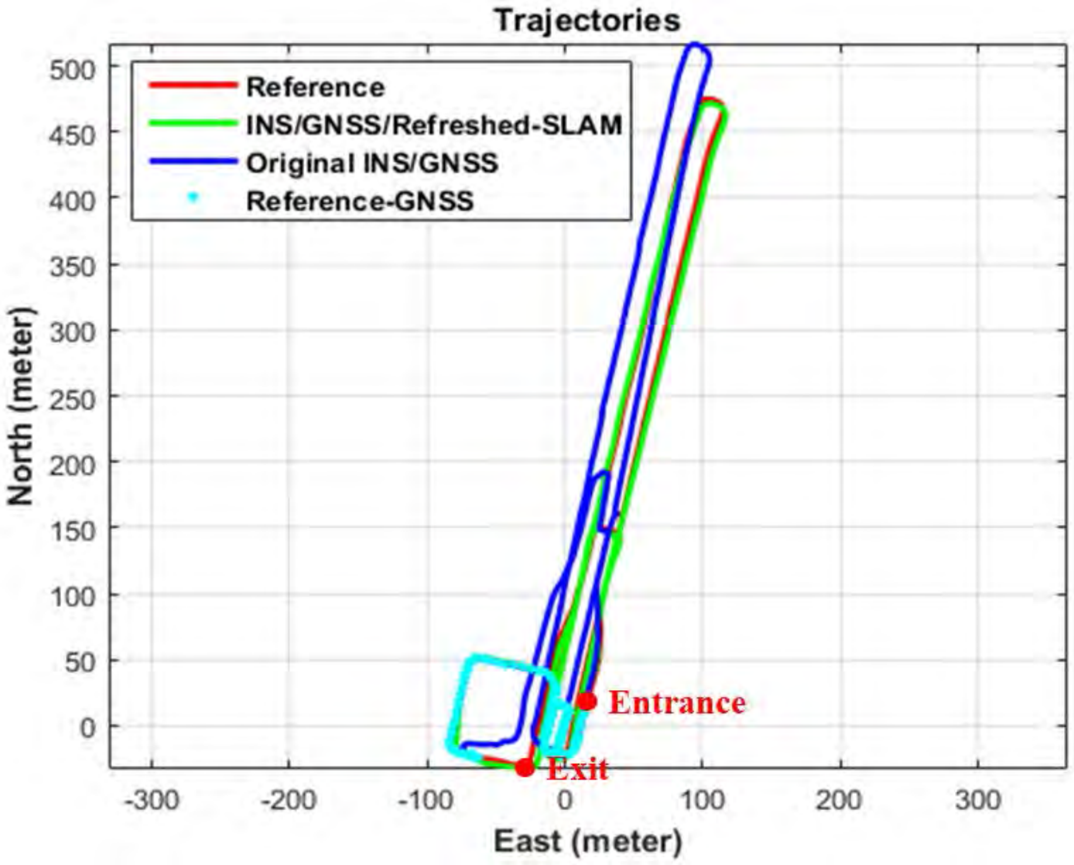


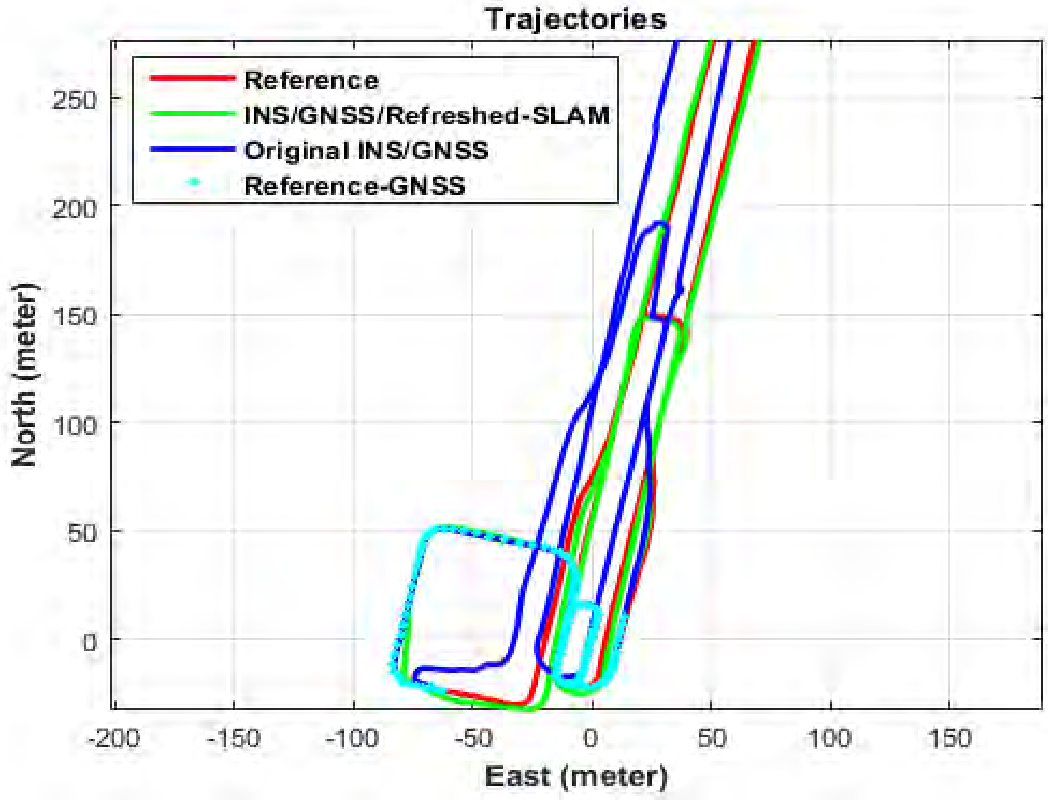




Lane Level Positioning : Strategies

- Test-2





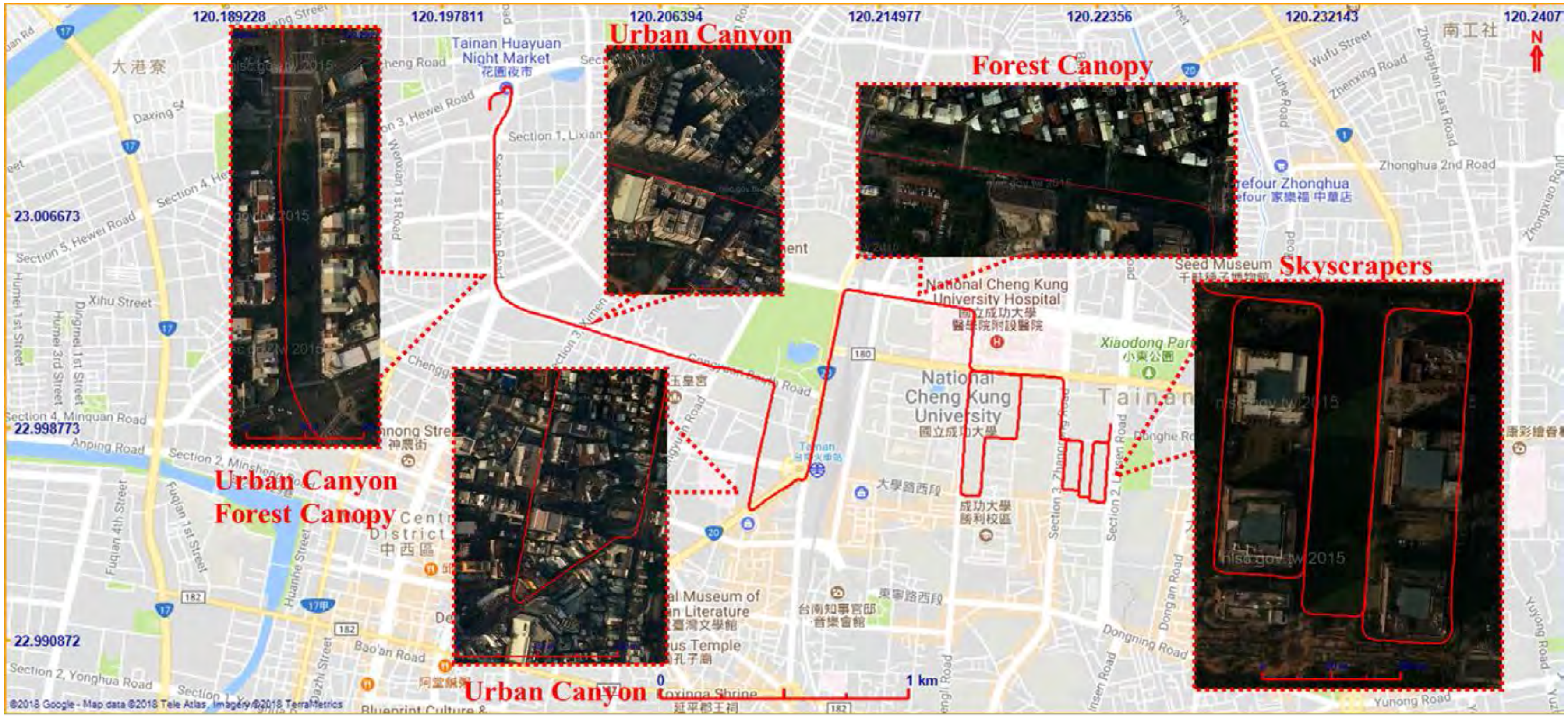
Lane Level Positioning : Strategies

- Test-2

	Original INS/GNSS			
Error	MEAN	STD	RMSE	Max.
North (meter)	-5.633	13.029	14.19	50.064
East (meter)	2.695	4.423	5.178	19.751
Height (meter)	0.47	0.464	0.66	1.504
Heading (degree)	-2.386	1.499	2.818	5.088
	INS/GNSS/Refreshed-SLAM			
North (meter)	1.103	1.73	2.052	5.646
East (meter)	-0.206	1.317	1.333	7.752
Height (meter)	0.187	0.423	0.462	1.428
Heading (degree)	0.335	2.126	2.151	3.454

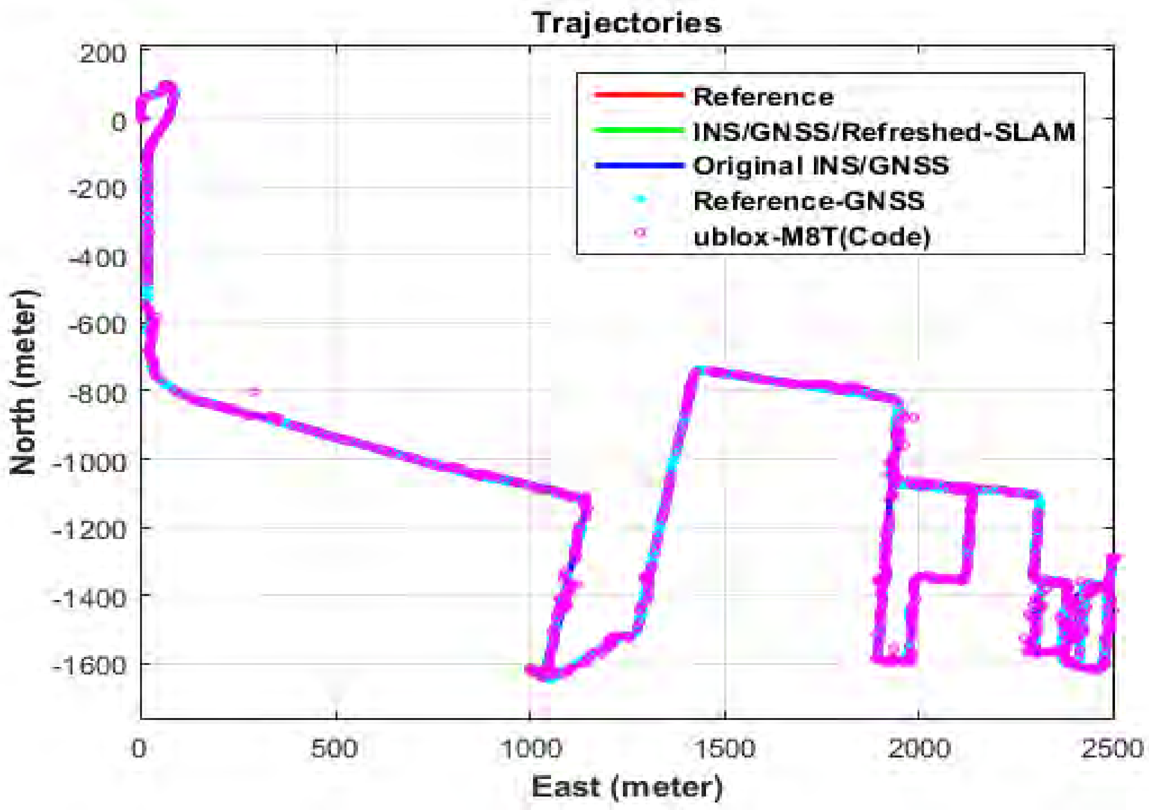
Lane Level Positioning : Strategies

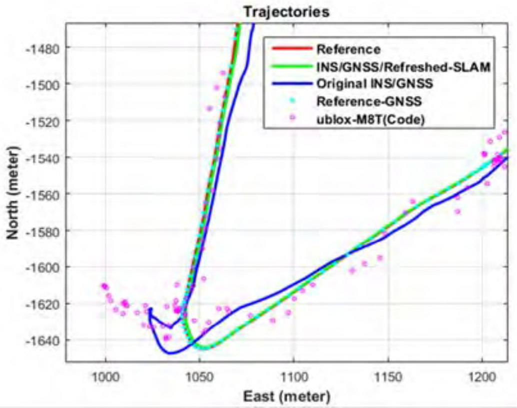
- Test-3
  - GNSS-hostile Environment
  - Single frequency GNSS module (Ublox M8T)

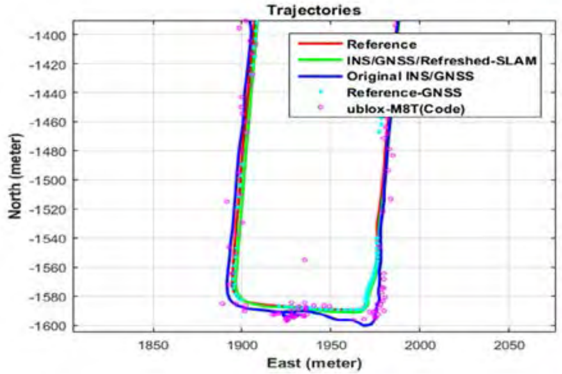


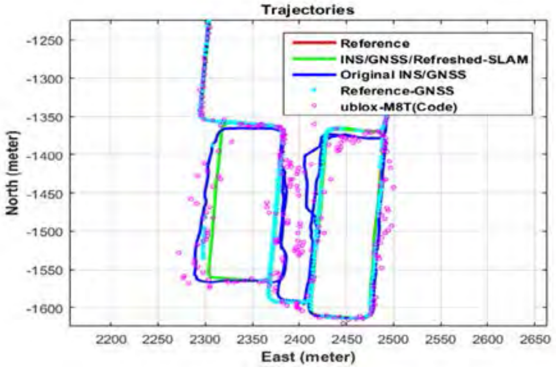
Lane Level Positioning : Strategies

- Test-3









Lane Level Positioning : Strategies

- Test-4

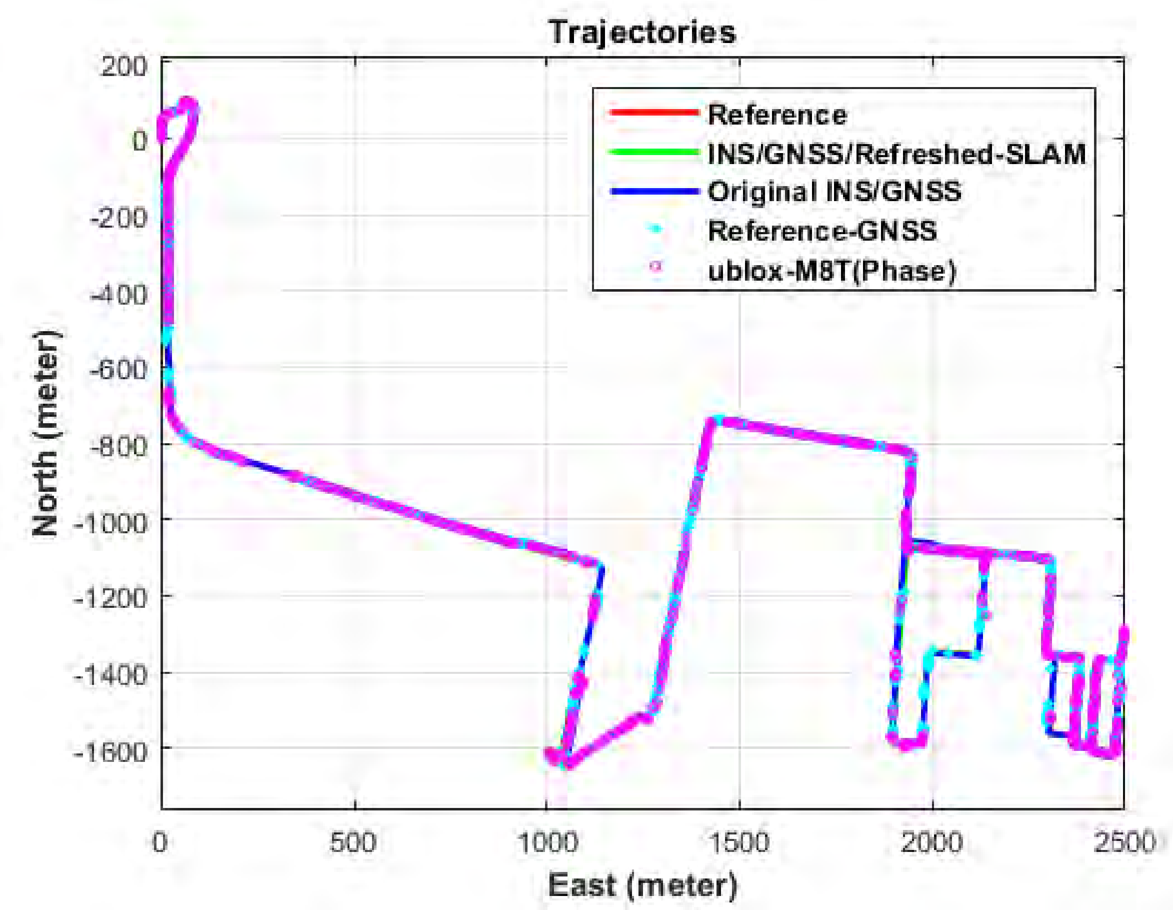
	Original INS/GNSS			
Error	MEAN	STD	RMSE	Max.
North (meter)	-0.370	3.390	3.409	11.773
East (meter)	-1.118	3.686	3.851	14.765
Height (meter)	-1.395	1.435	2.002	5.134
Heading (degree)	0.141	0.529	0.548	1.225
	INS/GNSS/Refreshed-SLAM			
North (meter)	-0.705	1.576	1.726	5.523
East (meter)	-0.756	1.718	1.876	7.099
Height (meter)	0.840	1.048	1.343	2.392
Heading (degree)	0.044	0.181	0.186	0.437

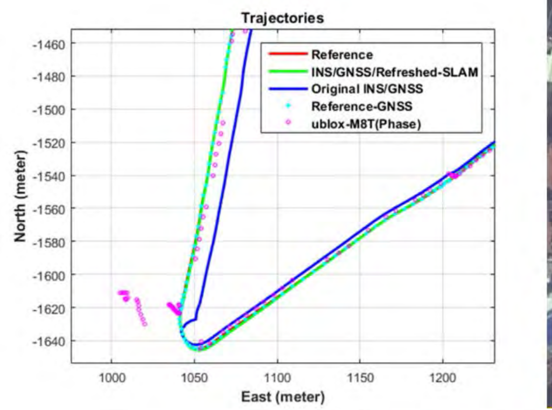
Lane Level Positioning : Strategies

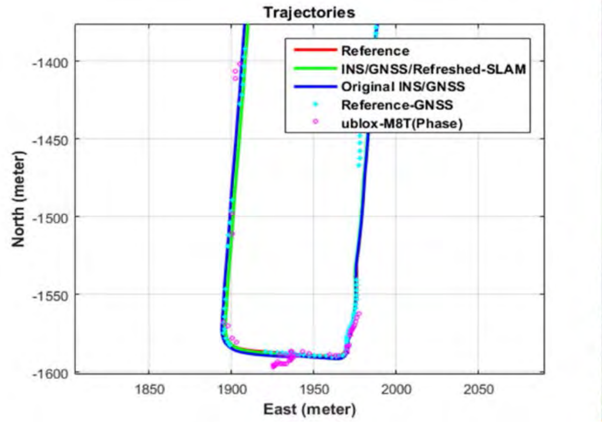
- Test-4

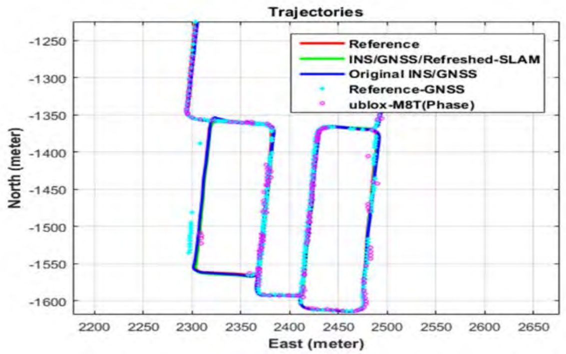
(a)

(b)









Lane Level Positioning : Strategies

- Test-4

	Original INS/GNSS			
Error	MEAN	STD	RMSE	Max.
North (meter)	-0.575	3.001	3.055	21.196
East (meter)	-1.323	2.848	3.140	11.325
Height (meter)	-0.461	1.33	1.407	3.578
Heading (degree)	-0.006	0.321	0.321	0.642
	INS/GNSS/Refreshed-SLAM			
North (meter)	0.137	1.244	1.252	5.729
East (meter)	-0.794	1.015	1.288	5.657
Height (meter)	0.829	0.982	1.285	3.121
Heading (degree)	0.007	0.133	0.133	0.346

Lane Level Positioning : Strategies

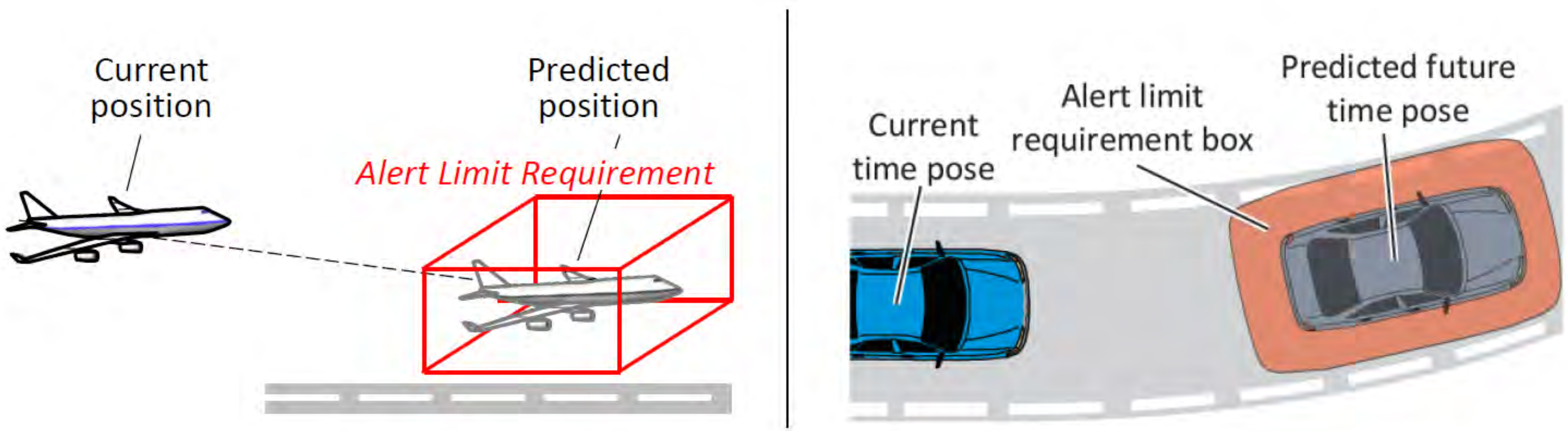
- Test-4

Lane Level Positioning : Strategies

- Test-4

Future developments

- Automotive safety issue



Challenges in bringing aviation safety standards to AVs

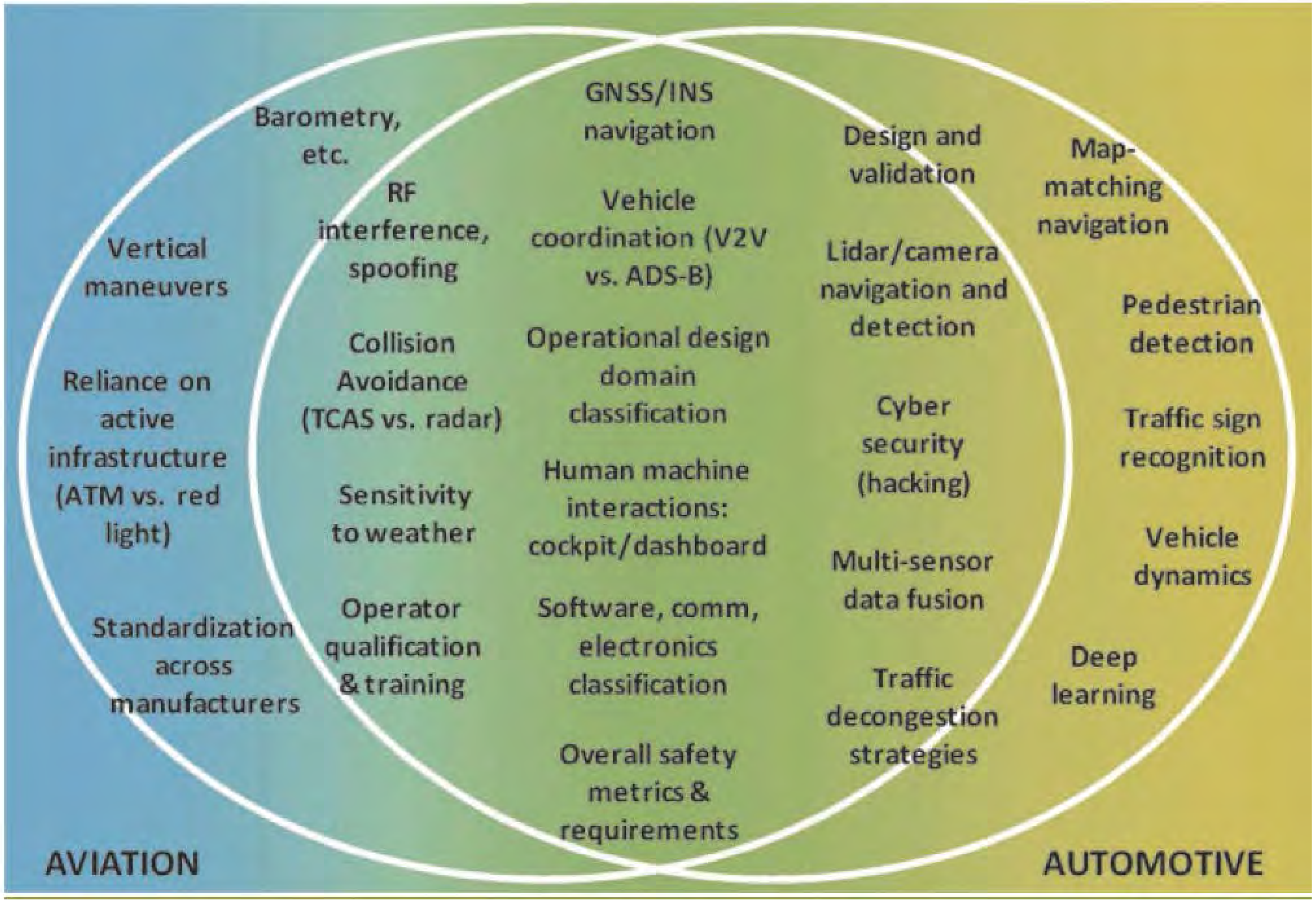
–GPS-alone is insufficient → **multi-sensor** system needed

–not only peak in safety risk at landing → **continuous risk monitoring**

–unpredictable meas. availability → **prediction** in dynamic AV environment

Future developments

- Automotive safety issue



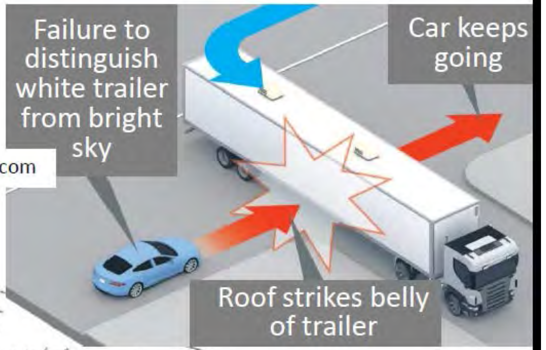
Future developments

- The AV environment is far more unpredictable than the aircraft’ s
  - A changing environment
  - Environmental diversity
  - Road users that may interfere with AV motion
  - Comparatively large number of car manufacturers, equipment suppliers, and vehicle models
  - Non-uniform vehicle and road regulations

Future developments

- Accident report for autonomous vehicles
  - In 2015, Google reported:
    - 13 'contacts' avoided by operator, Google car at fault in 10 of them [Google '15]
  - February 14 2016 in Mountain View, CA :
    - first crash where Google car was at fault
  - May 7 2016 in Williston, FL:
    - Tesla autopilot caused a fatality
  - March 18 2018 in Tempe, AR:
    - Uber car caused a fatality

http://jalopnik.com/



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