Cooperative localization Lessons learned from the Grand Cooperative Driving Challenge

Philippe BONNIFAIT
Professor
Université de Technologie de Compiègne
Heudiasyc UMR 7253
CNRS, France

High Quality Positioning: a Key to Success for Autonomous Driving

Title

- Introduction to the GCDC 2016
- Key components to do the challenge
- Architecture of the system developed at Heudiasyc
- Two scenarios during the challenge
- Lessons learned and perspectives

Grand Cooperative Driving Challenges

- GCDC 2011
  - A270 highway between Helmond and Eindhoven.
  - Cooperative platooning (sensor based-control with speed and acceleration exchange)
  - 9 teams (with cars and trucks)

- GCDC 2016
  - Same place
  - May 28-29, 2016
  - Autonomous driving with interactions with vehicles and infrastructure
  - Three different traffic scenarios
  - 10 European teams.

- Main Challenge
  - Cooperation between heterogeneous systems implementing different algorithms with different GNSS receivers

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Experimental vehicle

Fully electric car Renault Zoé, computer controlled

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GCDC 2016 Scenarios

- Scenario 1
  - Cooperative merging on highway
- Scenario 2
  - Cooperative intersection crossing
- Scenario 3
  - To give free passage to an emergency vehicle on a highway

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Snapshot of the GCDC 2016

Key components to do the challenge

Part 2

Communication

- Wireless comm on ETSI C-ITS standards
  - Both Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications.
  - ETSI ITS-G5 standard (GeoNetworking protocol and Basic Transport Protocol)
- Wifi mode, 5.9 GHz band (802.11p)
- Messages
  - CAM (Cooperative Awareness Message)
  - DENM (Distributed Environment Notification Message)
  - iCLCM (i-GAME Cooperative Lane Change Message)
- Broadcast frequency: 25 Hz

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CAM Message

Each vehicle had to implement a system estimating its geographical pose at 25 Hz

- Vehicle information
  - ID
  - Vehicle type (car, truck, etc.)
  - Vehicle role (emergency, roadwork)
  - Vehicle size (length and width)
- **Time Stamp**
  - **UTC time (in ms, ~1 minute ambiguity)**
- **Pose**
  - **Position (geo) + 95% confidence bound**
  - **Heading**
- Kinematics
  - Speed, drive direction, yaw rate
  - Acceleration

GNSS

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Time-stamping of the messages

- Synchronization of the computer time to the GPS time
- With an additional GPS receiver
  - Supplying 1PPS (one pulse-per-second) output
  - Open-source implementation of NTP, *chrony*
- Sub-microsecond accuracy

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Vehicle control

- For the GCDC, cruise control and platooning were mandatory
- Optional:
  - Cooperative platooning, Virtual platooning
  - Lane keeping, Lane changing

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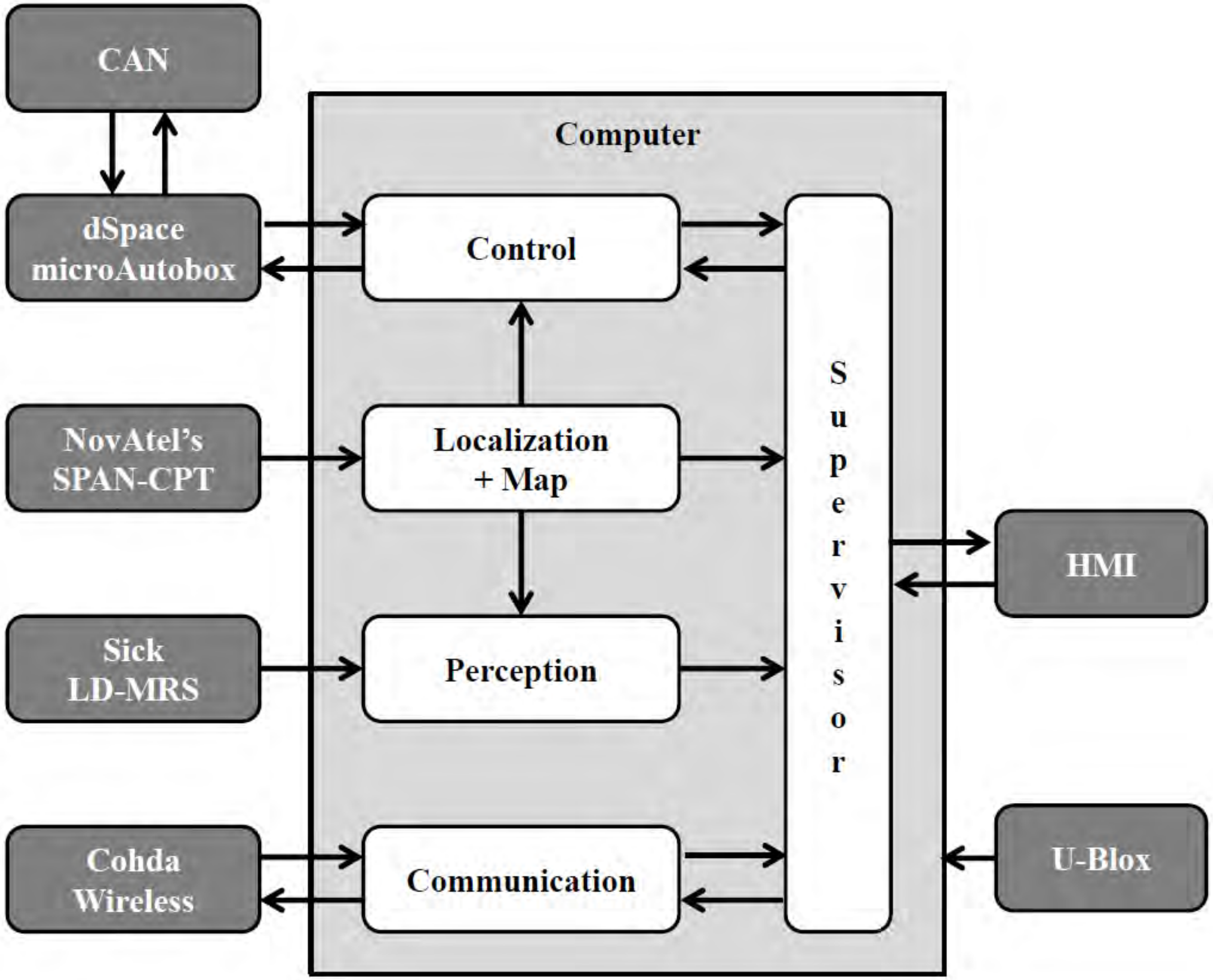
Architecture of the system developed at Heudiasyc UTC/CNRS

Part 3

System architecture



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Localization system

- NovAtel SPAN-CPT
  - Inertial Navigation System (INS)
  - Global Navigation Satellite System (GNSS)
  - GPS/GLONASS
  - Real-Time Kinematic (RTK) corrections (local base)
  - 50 Hz
  - Output: geographic coordinates (latitude, longitude, ellipsoidal height)
- Cartesian Frame
  - East, North, Up (ENU) coordinates with local origin
  - 2D pose computation
  - Cartesian coordinates are much more practical than Geodetic coordinates
  - Homogeneous transformation (no projection) perfectly invertible

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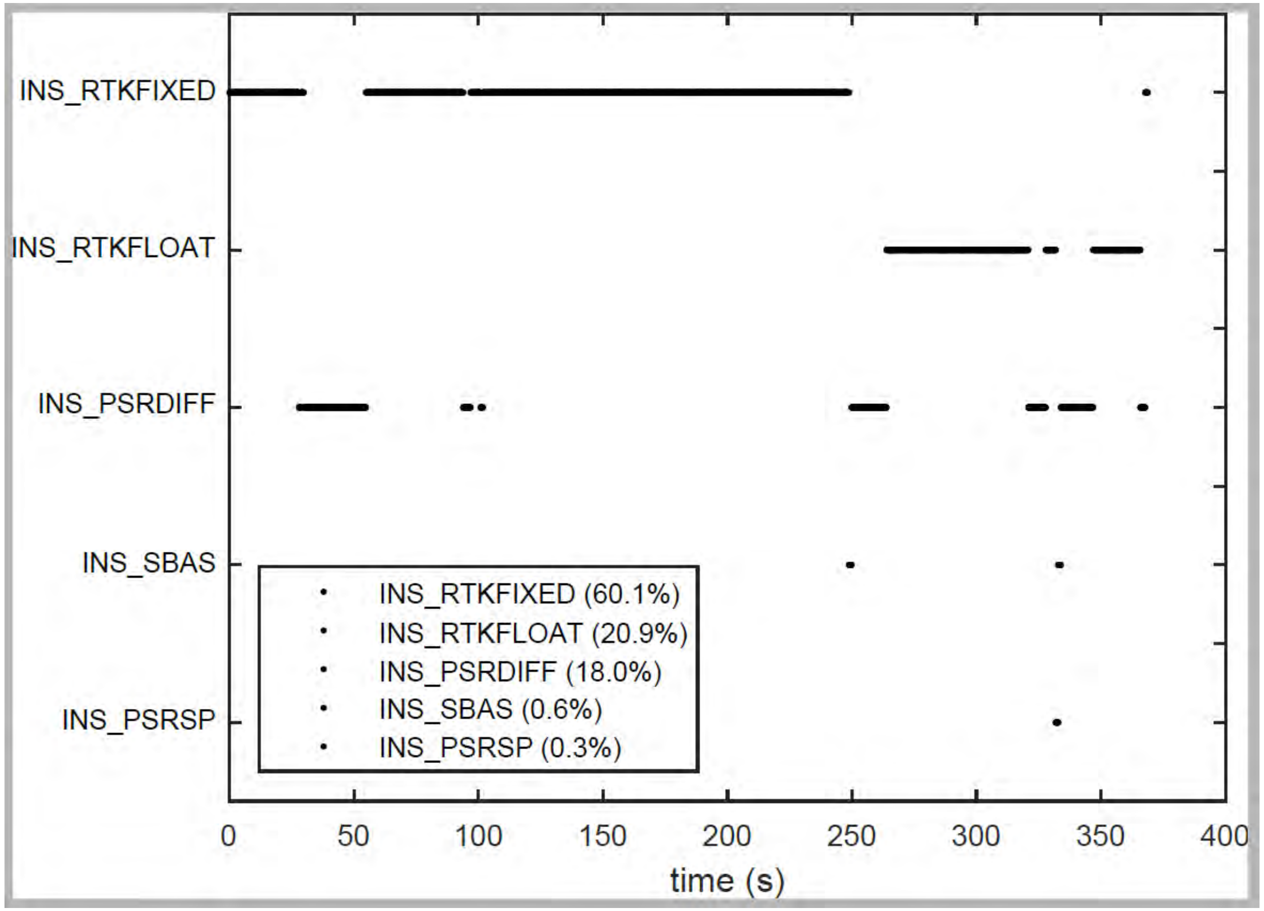
SPAN-CPT positioning modes with their typical accuracies

Positioning mode	Accuracy
RTK fixed ambiguities solution (RTKFIXED)	~ 0.01 m
RTK floating point ambiguities solution (RTKFLOAT)	< 1.0 m
Pseudorange Differential Solution (PSRDIFF)	< 2.0 m
Satellite-Based Augmentation System (SBAS)	~ 3 m
Pseudorange Single Point Solution (PSRSP)	~ 5 m

Modes during a complete merging heat



80% of the time: GNSS with sub-metric accuracy

With the data-fusion of the IMU: enough accuracy to do path following

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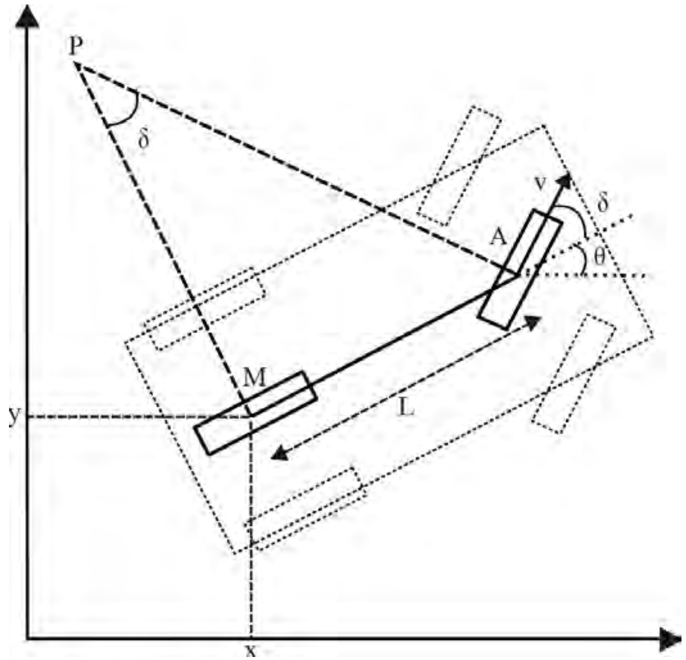
GNSS-based lateral control

- Path following and steering control using SPAN-CPT pose estimates
- Lane change between two adjacent lanes: switching from the current lane to the new lane without path planning



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Map

Map provided not accurate enough

➔ Built online during the first trial of the challenge (center paths of each of the two lanes of the highway)

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Two scenarios during the challenge 28-29 May 2016

Part 4

Scenario 1: merging

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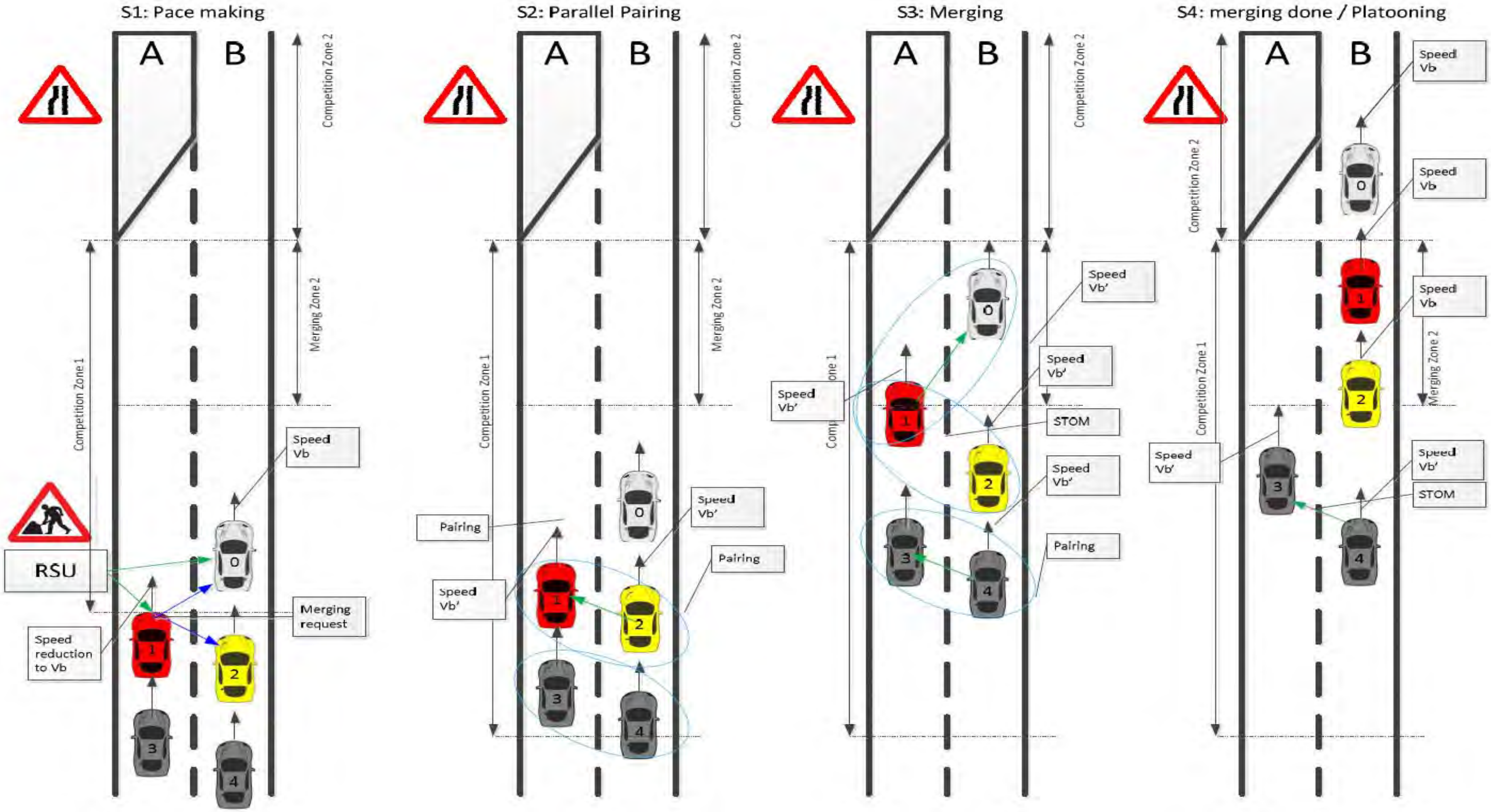
Merging procedure



Merge request

Pairing
Red is the new leader of the yellow

Enough space to merge

3 can start merging

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Merging during the challenge

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What we did in practice

- Since the received positions were not enough reliable, we took the decision to not use the GPS position of the others to do platooning and pairing
- Platooning
  - using Lidar only with the vehicles in front
- Pairing
  - We used the list of the participants given by the organizers at the beginning of every heat

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Scenario 2: Intersection crossing

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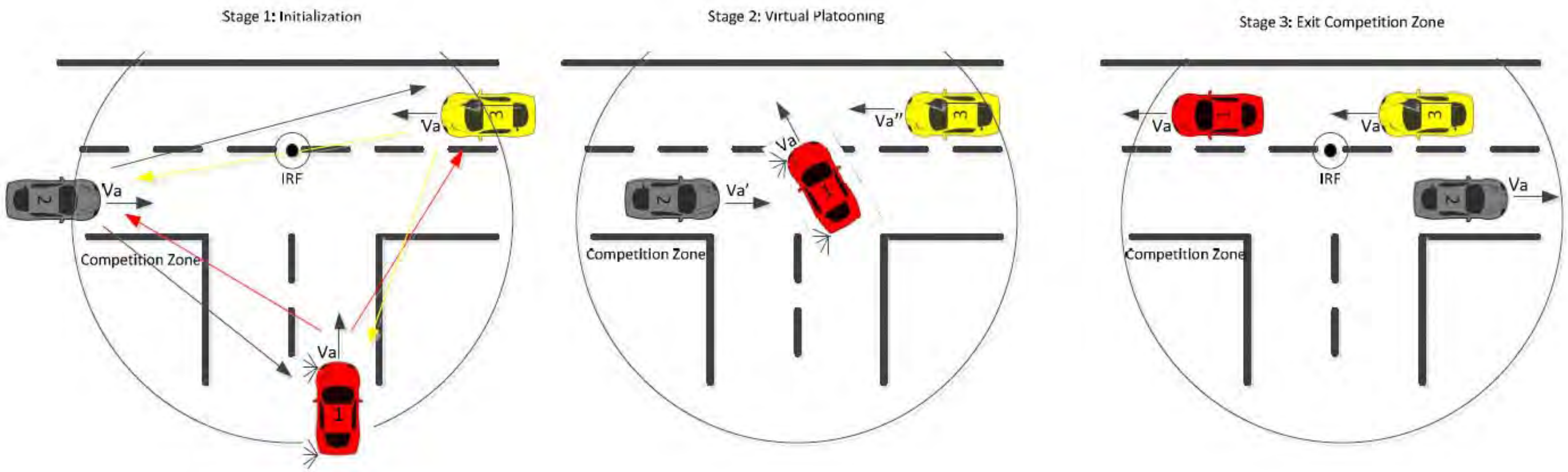
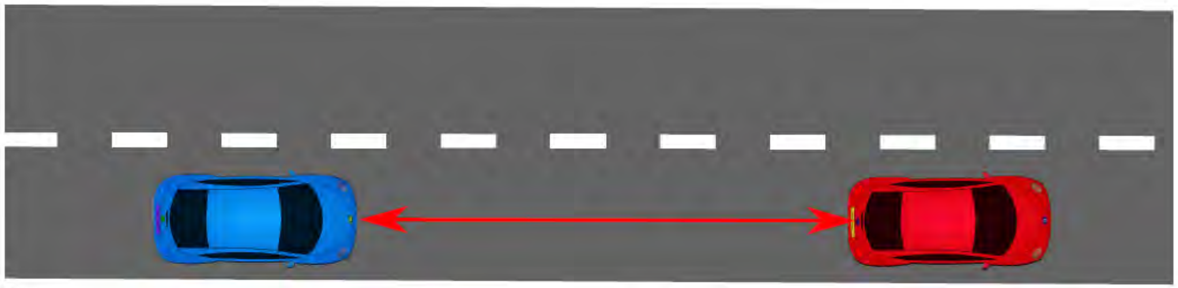
Intersection crossing

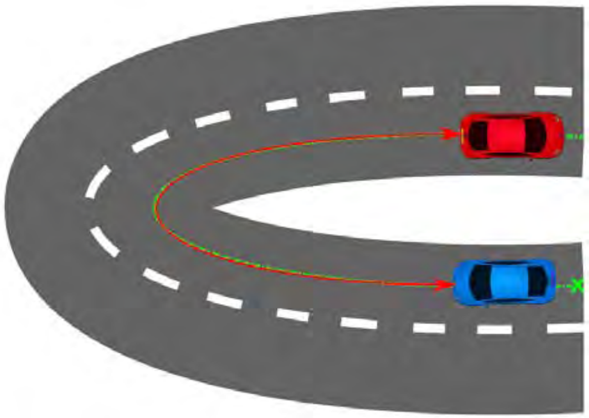


- 1 is a vehicle of the organizers
- The challengers are 2 or 3
- Goal:
  - Vehicles 2 and 3 have to let vehicle 1 cross the intersection at constant speed

Inter-distance for platooning

In straight road, inter-distance is easy to measure (Lidar)





In curved road, compute the inter-distance along the map by using GNSS positions

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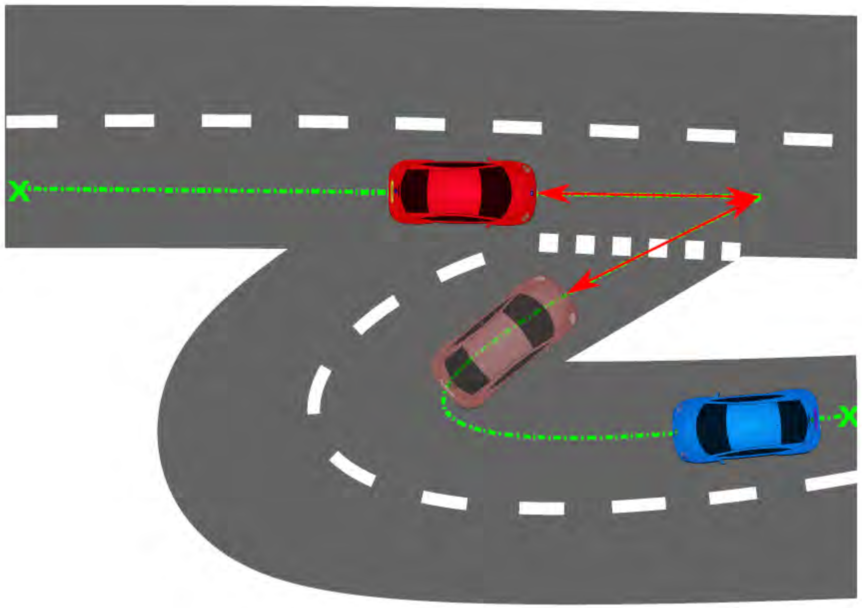
The virtual platooning concept

Every vehicle computes its distance to the crossing point such that the others can locate it on their own path



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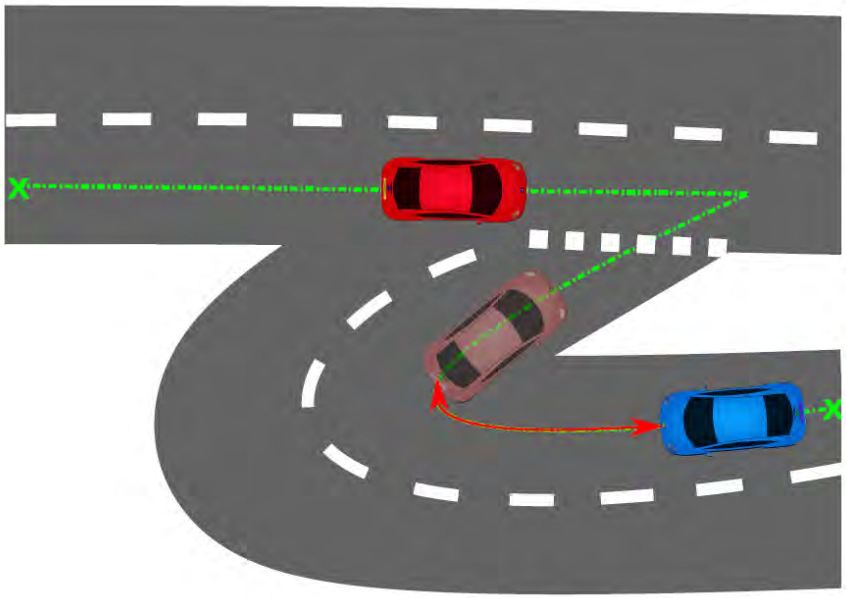
The virtual platooning concept

- Here, the vehicle that is the closest to the intersection point becomes the (virtual) leader
- Then the blue one does platooning



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What we did in practice

- We did virtual platooning with the vehicle of the organizers
- We used its transmitted position **because we knew it was reliable**
- Procedure:
  - Set the origin of the frame at the center of the intersection
  - Convert the geo-positions in this frame
  - The norm of the position is the distance to the center
  - Do virtual platooning until the car has crossed the intersection

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Lessons learned

Part 5

GNSS and autonomous cars

GNSS is crucial for:

1. Stand-alone navigation with maps
2. Cooperative navigation with the other road users

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GNSS positioning is mandatory for navigation tasks each time a computation is done in the virtual world

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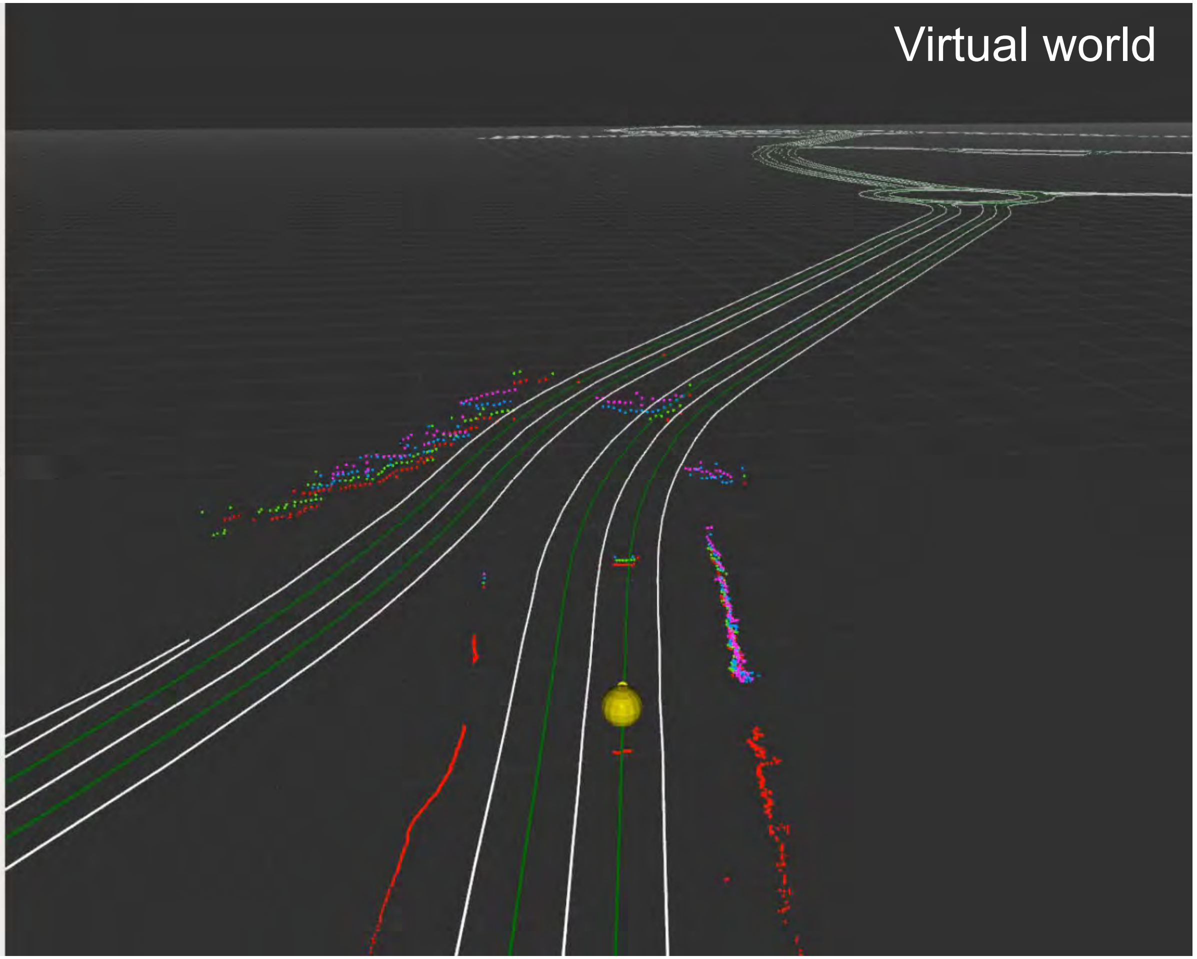

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Stand-alone navigation with maps

- Path following with GNSS
  - In lane (P<0.1m, 50%) - lateral
- Monitoring of the autonomous driving capability of the car on the current navigation area (motorway, etc.)
  - Lane-level (P<0.4m, 50%) - lateral
- Anticipation of a dangerous area (e.g. slow down when approaching a tiny curve or an intersection)
  - Carriageway-level (P<4m, 50%) - longitudinal

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GNSS for cooperative navigation

- Decisions are based on the position of the vehicle itself and of other vehicles in its vicinity.
- Cooperative merging
  - Localization can be used for associating the perceived vehicles and the received messages (to identify who wants to merge and at what location)
  - Lane-level (P<0.4m, 50%) (such that there is no ambiguity)
- Intersection crossing
  - Localization is useful for improving crossing procedures in case the vehicles can’t see each other
  - Lane-level (P<0.4m, 50%).

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GNSS for cooperative control

- Localization is useful for cooperative systems at the control level when the others traffic participants are **out of view**
  - Lane change, overtaking, intersection crossing
  - Lane-level (P<0.4m, 50%)
- Localization errors may lead to dangerous situations for cooperative control when the others traffic participants are in the vicinity
  - Inter-distances in platoons have to be regulated with embedded perception sensors
  - When crossing junctions, embedded perception sensors are necessary for a safe navigation

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Integrity

- If vehicles estimate protection levels of position errors reliably and send them to the others, then complex cooperative tasks can be solved safely
- Basic principle: be pessimistic to ensure safety
- Not optimal and may reduce system availability

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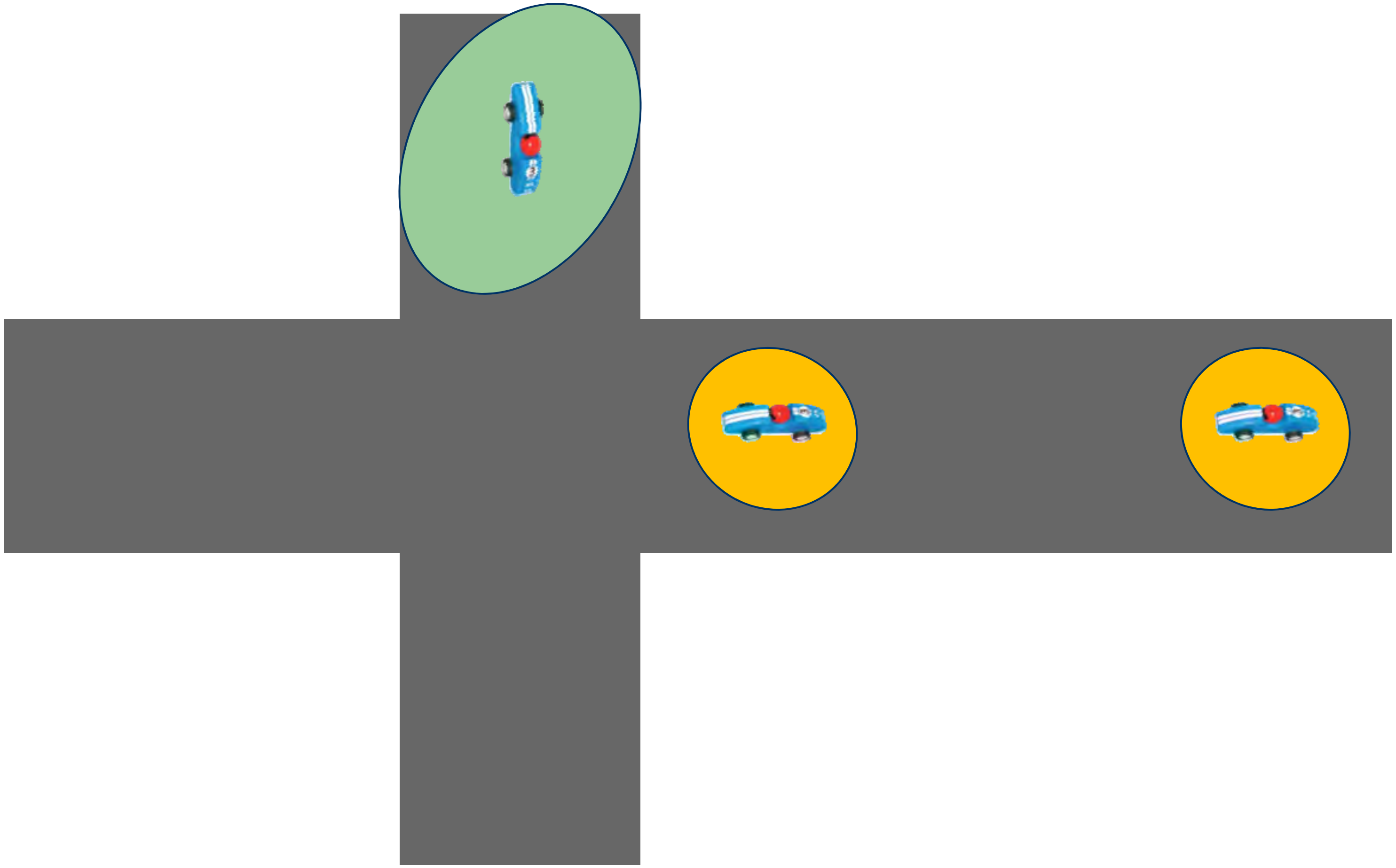
Illustration



Conclusion

- GNSS is essential for autonomous cars
- Vehicles exchanging dynamic information with each other is a new paradigm to improve autonomous vehicle navigation
  - Useful to reduce the number of embedded sensors for navigation
- Reliable bounds of localization errors are essential for
  - Stand-alone navigation with maps
  - Cooperative navigation

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THANK YOU FOR YOUR ATTENTION !

Philippe BONNIFAIT
Professor at the Université de Technologie de Compiègne
Heudiasyc UMR 7253 CNRS, France
philippe.bonnifait@hds.utc.fr