Autonomous cars navigation on roads opened to public traffic: How can infrastructure-based systems help?

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Autonomous cars navigation

Cars don’t drive in opened spaces

The navigation space is constrained and there are interactions between cars.
Main question addressed in this talk

How can a car see far enough with a reasonable set of embedded sensors?
Outline

1. Level of autonomy of autonomous vehicles
2. Key elements for cooperative autonomous navigation
3. Cooperative navigation example: vehicle2vehicle communication
   1. Intersection crossing
   2. Platooning
4. Infrastructure-aided Systems
   1. Lane Merging
   2. Roundabout crossing
5. Conclusion and perspectives
Level of autonomy of autonomous vehicles

Part 1
Autonomous Vehicles: Trends

- Driverless vehicles
  - New Mobility Services
  - Shuttles and Robot taxis

- Autonomous cars
  - Traditional customers
  - Valet vehicle
  - Traffic Jam Assist

[Images of autonomous vehicles]
Robot vehicle

Ability to function independently of a human operator in any context

Operational autonomy

- Feedback mechanisms to control behavior to follow a predefined trajectory, while rejecting disturbances
- No need for user monitoring

Decisional autonomy

- The machine has the ability to understand and take safe decisions despite the uncertainties of perception and localization as well as incomplete information about the environment
The three roboticist axes

Autonomy ability
Independence with respect to human

Complexity of the environment and of the navigation area

Complexity of the mission or task
Example of autonomous car: Valet Vehicle (PAMU Renault)
The valet vehicle of the roboticist axes

Autonomy ability
Independence with respect to human

Complexity of the environment and of the navigation area

Complexity of the mission or task

Valet Vehicle
Cooperation as a mean to increase abilities of autonomous cars

**Autonomy ability**

**I want my car to have a high level of autonomy**

**Complexity of the environment and of the navigation area**

**Complexity of the mission or task**
Key elements for cooperative autonomous navigation

Part 2
Sources of information for autonomous navigation

- Exteroceptive sensors
- GNSS receiver
- Digital maps
- Proprioceptive sensors
Localization and perception

Localization system
— allows the vehicle to position itself spatially, absolutely or relatively, in its evolution environment

Perception system
— equips the vehicle with understanding and prediction capabilities of its immediate environment. From the sources of information available, the vehicle builds a representation of the environment that allows it to navigate
Localization and perception

World Model

Real world
Wireless communication for cooperative autonomous navigation

Exteroceptive sensors

GNSS receiver

Wireless communication means

Digital maps

Proprioceptive sensors
Wireless Networks for data exchange

Vehicular ad hoc networks (VANETs) allow an augmented perception of the dynamic environment by using wireless communications:

— Vehicle-to-Vehicle (V2V)
— Infrastructure to Vehicle (I2V)

Some typical messages (ETSI standard)

— CAM (Cooperative Awareness Message)
— DENM (Distributed Environment Notification Message)
— CPS (Collective Perception Service - ETSI TR 103 562 under preparation)

Features

— short range radio technologies (Wifi mode), 5.9 GHz band (802.11p)
— Broadcast frequency: 1-10 Hz
CAM Message (V2V)

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
DENM Message (I2V)

Sent by Road Side Units (RSU)

Data :

- Station type
- Time Stamp
- Event type
  - Roadworks,
  - Stationary vehicle,
  - Emergency vehicle approaching,
  - Dangerous Situation, etc.
- Lane position
- Lane is closed or not
CPS Message (I2V)

Can be emitted by the infrastructure or the vehicles.

Information:
- List of detected objects
- Position, speed, acceleration
- ID and type of the sensor which provided the measurement data

Diagram:
- High-level object fusion
  - Data fusion specific to ITS-S manufacturer
  - Low-level data management
  - CP Basic Service
- ADAS applications

Diagram:
- Low-level object fusion
  - Sensor 1
  - Sensor n
  - Data fusion specific to ITS-S manufacturer
  - CP Basic Service
- ADAS applications

Diagram:
- ADAS applications
- CP Basic Service

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Typical processing loop

1. **Acquisition**
   - Sensors, maps and wireless information

2. **Localization and perception (world modeling and understanding)**

3. **Decision, planning and control**

   - Wireless communication
   - Localization and perception information

   - Actions
Cooperative navigation example: intersection crossing with V2V data Exchange

Part 3
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
Heudiasyc team

Team Leader:
Philippe XU

People involved
— 5 Profs and Researchers
— 3 Engineers
— 2 Phd students
— 2 interns
— 12 Master students
Experimental vehicle

Fully electric car (Renault Zoé)
Maximum speed of 50 km/h while driving autonomously
Snapshot of the GCDC 2016
Inter-distance for platooning

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

In curved road, compute the inter-distance along the map by using positions exchanged by wireless communication
Cooperative merging using virtual platooning
The virtual platooning concept

Every vehicle

- Computes its distance to the crossing point
- Such that the others can localize it on their own path
The virtual platooning concept

In this example, the red vehicle is the closest to the intersection point and becomes the (virtual) leader. Then the blue one does platooning.
Vehicle 1 is a car of the organizers, the challengers are 2 and 3.

Goal:
- Vehicles have to reach the competition zone at a given time with a given speed.
- Vehicles 2 and 3 have to let vehicle 1 cross the intersection at constant speed.
- The goal of each challenger is to exit the CZ as fast as possible (with no collision).
Snapshot of an intersection crossing during the GCDC
Cooperative Wireless platooning with CAM Messages

Experiments at Compiègne
Cooperative navigation with Infrastructure-based Warning systems

The merging example

During the GCDC
GCDC Scenario: Merging

A lane is closed (e.g. road work)

A RSU broadcasts this event using a DENM message.
Lanes merging snapshots
Merging procedure

S1: Pace making

Merge request

S2: Parallel Pairing

Pairing
Red is the new leader of the yellow

S3: Merging

Enough space to merge

S4: merging done / Platooning

3 can start the merging process
Initialization of a merging scenario
Merging during the challenge
Cooperative navigation with Infrastructure-based perception systems

The roundabout crossing example

Tornado project
The infrastructure scans the environment and it shares information about the current traffic participants by broadcasting the locations and speeds of the mobile objects. This reduces the ambient uncertainty by providing contextual information.
Case study: Roundabout crossing

• Infrastructure can assist autonomous cars to cross roundabouts by detecting and broadcasting CPM messages with vehicles positions and speeds inside the roundabout.

• Thanks to this, autonomous vehicles can anticipate crossing the roundabout by adapting their speed.
Adapting the Virtual Platooning Concept to Roundabout Crossing

- Use a high-definition map (HD map)
- Map-match every estimated position
Virtual Platooning in a Roundabout

- Compare distances between vehicles and a common node
Virtual Platooning in a Roundabout

• Place the other car on your own path.
• Determine the leader
Virtual Platooning in a Roundabout

- The red car is the leader which is followed by the green one
Guy Deniélo Roundabout (Compiègne)
Example with cooperative autonomous cars
Conclusion and perspectives
Conclusion

Cooperation is a new paradigm for autonomous vehicles navigation

Thanks to wireless communication, vehicles can
  — Receive information from the infrastructure
  — Exchange highly dynamic information with the others

Localization is crucial since most of the decisions are based on the location of the vehicle itself and of other vehicles in its vicinity

Cooperation is useful
  — For augmented perception
  — For anticipation
  — For cooperative maneuvers
  — To reduce the number of embedded sensors for navigation
Cooperation for autonomous cars

Infrastructure to car information
(one way)

Car to car information
(cycles)
Perspective

Progress to be made

— Methods that guaranty the integrity of the information exchanged and control the propagation of errors and faults
  — In particular, cycles of exchange inducing data incest problems have to be taken into account
— Methods able to compute in real-time reliable bounds of the errors
— Data exchange standards
  — In particular, regarding the uncertainty representation
Thank you for your attention!

Associated publications


• E. Héry, Ph. Xu and Ph. Bonnifait. “Along-track localization for cooperative autonomous vehicles”. IEEE Intelligent Vehicles Symposium, Redondo Beach, California, June 2017.

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