Annual activity report

year 2019/2020

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XXXIV Cycle

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POLITECNICO DI TORINO

PhD scholarship funded by CARS@PoliTO

Macroarea

Design, modeling, and control of Autonomous vehicles

Research goals

- Autonomous vehicles: DESIGN
- Autonomous vehicles: MODELING
- Autonomous vehicles: CONTROL

SIDE PROJECTS

- Design of intelligent algorithms for the estimation of vehicle dynamics parameters (sidesling angle and longitudinal speed)
- Design of intelligent algorithms for the estimation of the SOC and SOH for Lithium batteries in automotive industry

Further research activities

- Design and implementation of steering and braking actuation systems for a driverless electric racing vehicle.
- Design and implementation of a monitoring system for the state of charge and health of lithium batteries for the automotive industry.
- Design of an algorithm to monitor the state of climbing ropes with artificial intelligence.

Autonomous vehicle: design at a system level – state of the art and current approach

1. PERCEPTION

stereocamera

LIDAR

Obstacles detection

Obstacles distance estimation

CPU with embedded GPU

2. TRAJECTORY PLANNING

Investigated algorithms:

Probabilistic Road Map (PRM)

Rapidly-exploring Random Tree (RRT)

3. CONTROL

Model Predictive Control (MPC)

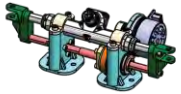
Vehicle modeled as a linear 3-DOF model

4. ACTUATORS

Braking actuator

Remote Emergency System

Steering actuator



ROBUST POSITIONING

GPS + IMU + odometry

EXPERIMENTAL APPROACH

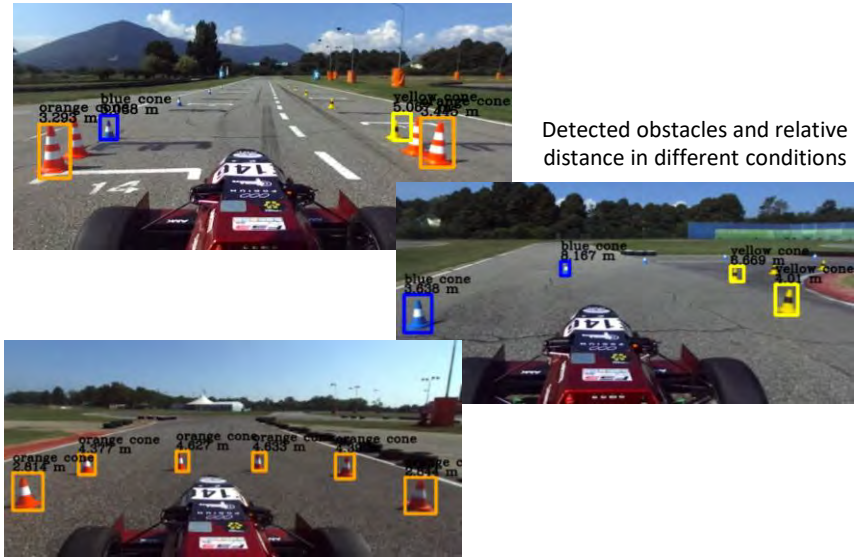
DESIGN -> SIMULATION -> TESTING

all the algorithms and actuators are designed and tested on a real electric 4WD racing vehicle

Autonomous vehicle: perception algorithms – experimental results

- **Stereocamera** 

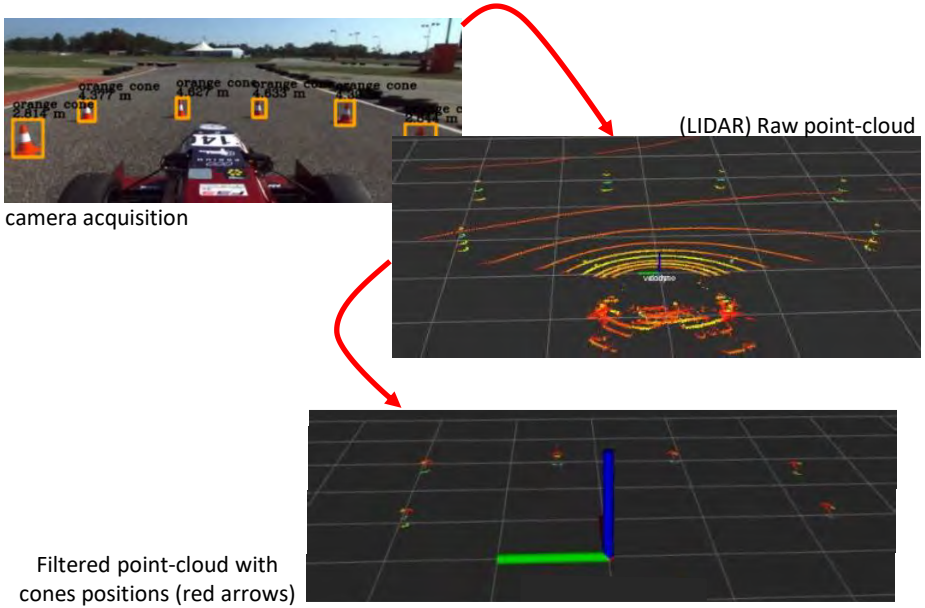
  - Inverse mapping of right and left images from the sensor by means of a SSD (single shot detector) exploiting a SVM-based (support vector machine) algorithm and ANNs (artificial neural networks) to detect the obstacles.
  - Information about obstacles is retrieved (color, distance, position).
  - Combining the RGB matrix in the images with the related depth map computed from the stereocamera.



Detected obstacles and relative distance in different conditions

- **LIDAR** 

  - According to the need of having a fully redundant system and to improve the perception accuracy, the LIDAR sensor is used to detect obstacles.
  - It is used by means of ground removal and point-coud clustering algorithms, using Voxel-type ANNs and SVM-based algorithms.



camera acquisition

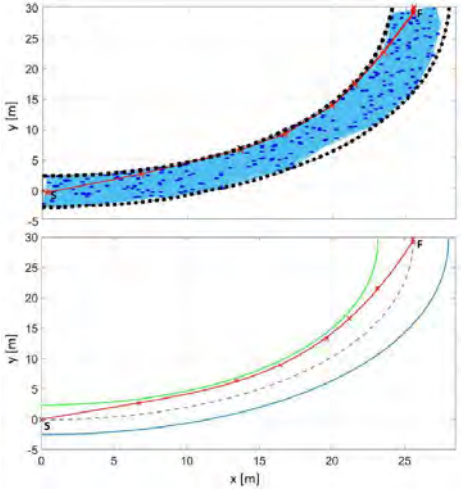
(LIDAR) Raw point-cloud

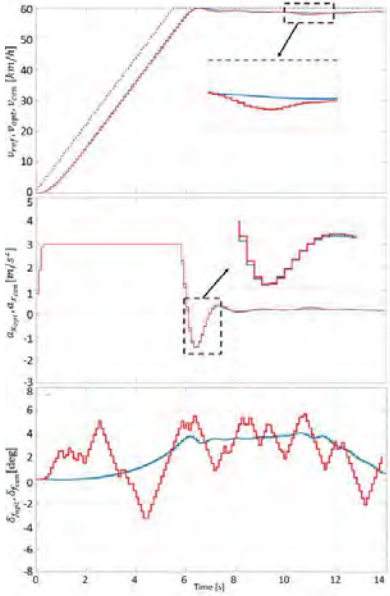
Filtered point-cloud with cones positions (red arrows)

Autonomous vehicle: trajectory planning – obtained results

- **Probabilistic Road Map (PRM)**

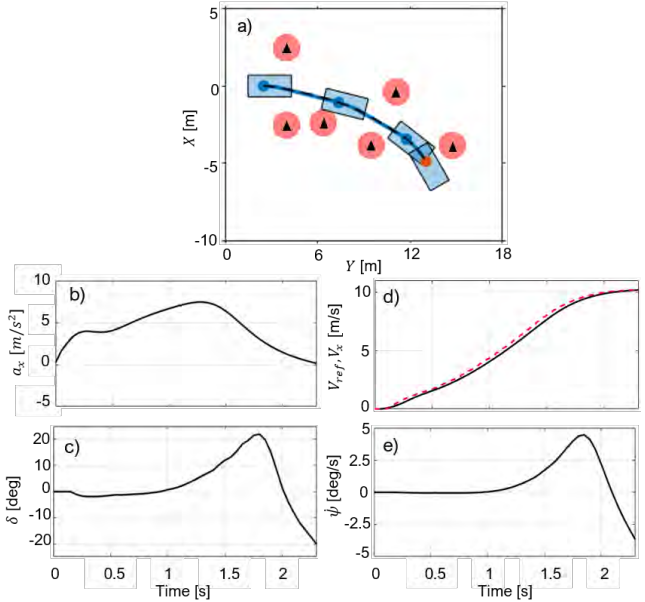
  - Easy design of the algorithm
  - Improved performance with respect to the central line approach
  - Heavy computational burden…
  - …thus not deployable on the chosen controller





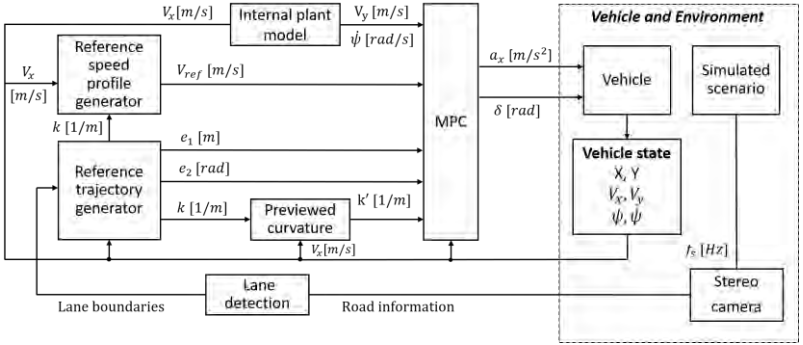
- **Rapid-exploring Random Tree (RRT)** ← chosen for implementation in a dSPACE control platform

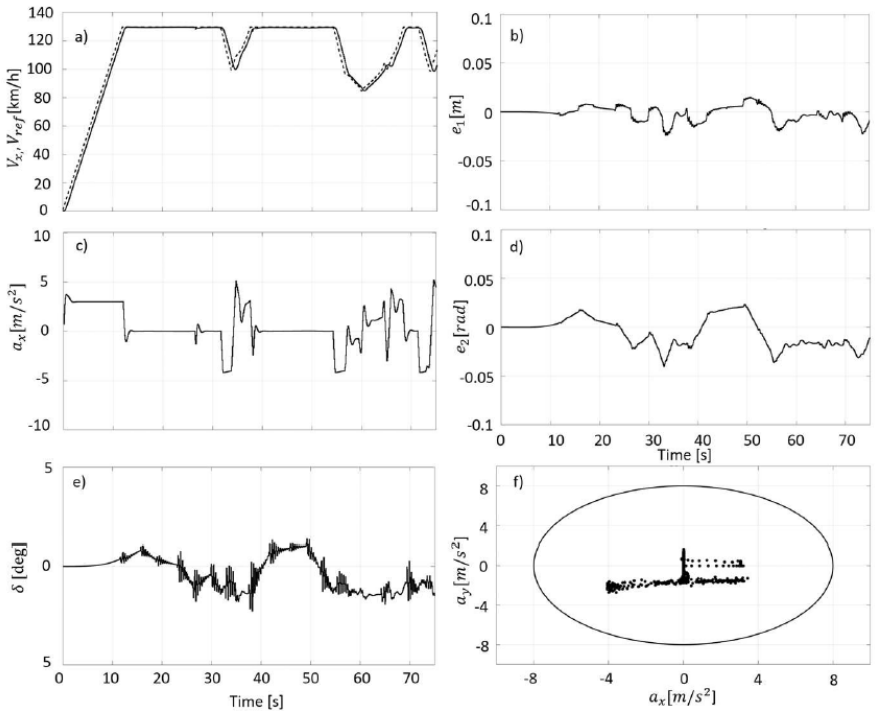
  - Lower computational cost
  - Very good performance
  - Suitable for stuctured driving environment
  - Accurate in different driving scenarios



- **Model Predictive Control (MPC)**

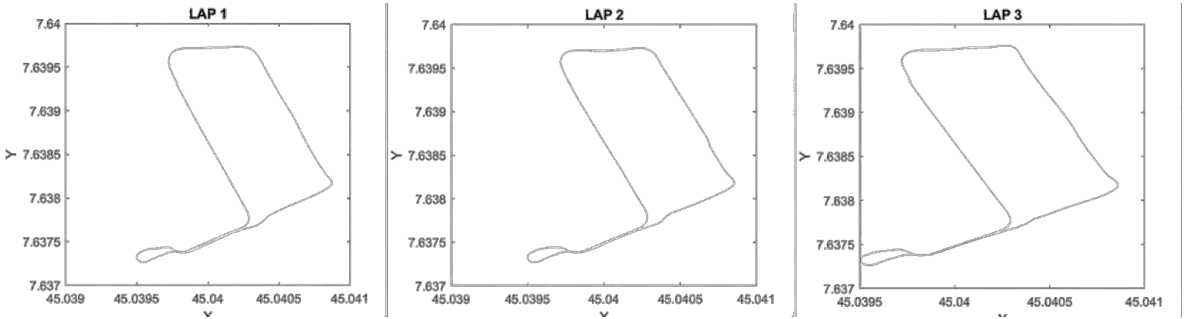
- The designed controller for trajectory tracking and speed regulation is based on the MPC approach.
- The vehicle is modeled as a 3-DOF linear model.
- The controlled variables are: lateral deviation and relative yaw angle, computed with respect to the planned trajectory.
- The control output are: steeering angle and longitudinal acceleration.

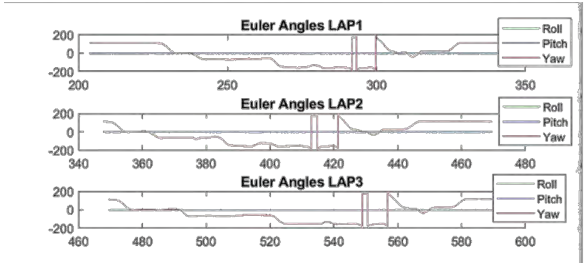


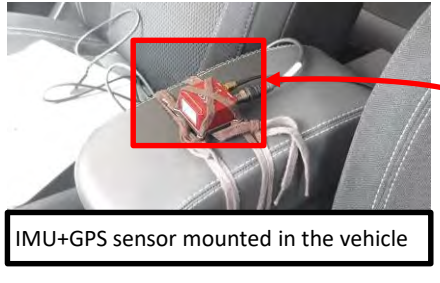


- **GPS + IMU + visual odometry**

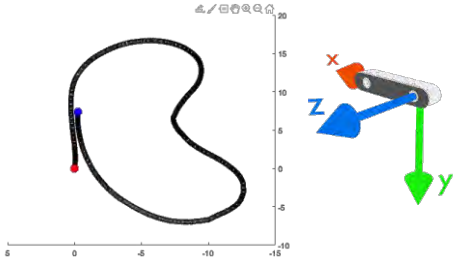
- A Robust Positioning algorithm is needed for the evaluation of the vehicle's path and to enable further global mapping algorithms.
- Localization of the vehicle is crucial in the driving environment
- An Extended Kalman Filter (EKF) has been implemented exploting the sensor fusion of signals computed by a GPS sensor, an IMU and stereocamera that provides a visual odometry.
- Real-time Corrections (RTK method) with an additional GPS sensor is currently under research for next activities.
- The final goal is to obtain a geo-referenced assessment of the vehicle inertial localization with centimeter accuracy.







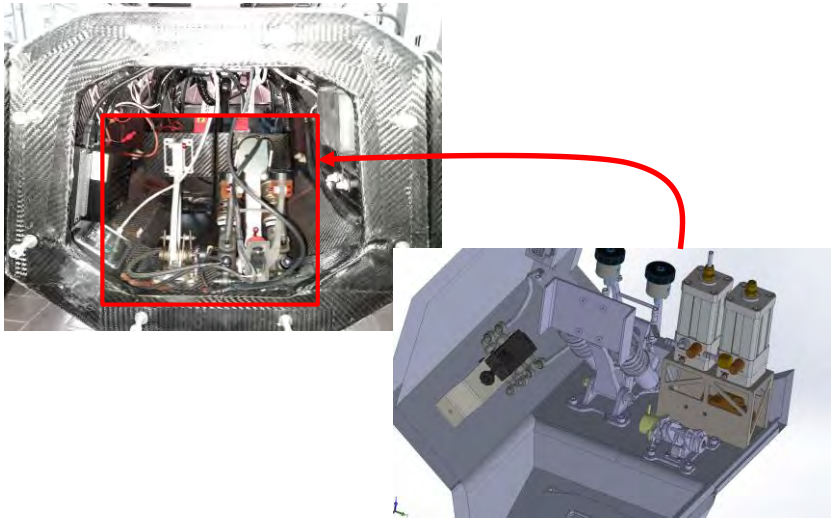
IMU+GPS sensor mounted in the vehicle



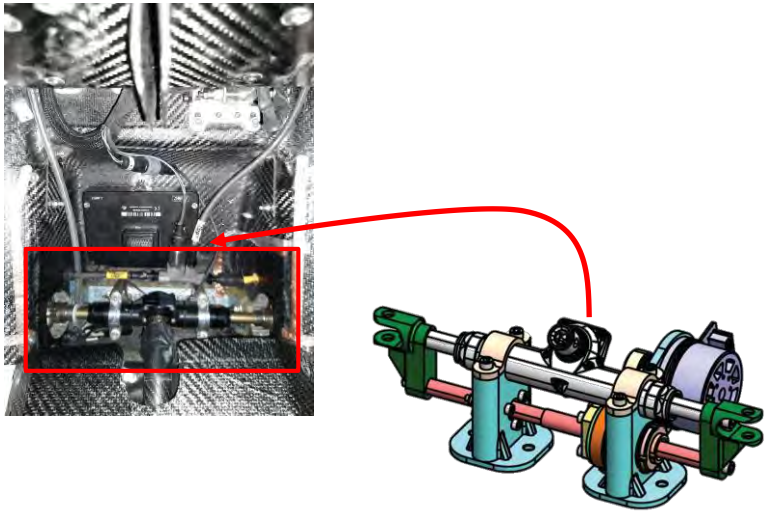
Visual odometry results

Autonomous vehicle: actuators – system design

- **Braking actuator**
  - Fully redundant system (actuation directly on the brakes master cylinders)
  - System controlled remotely by a wireless Remote Emergency System (RES)
  - Actuation time < 0.15 s (starting from the remote emergency signal)
  - Operating pressure = 40 bar (but canisters are refilled at 300 bar)
  - Custom design high and low pressure pneumatic lines and actuators



- **Steering actuator**
  - Brushless motor: MAXON 150 W, 24 V
  - Ball screw system
  - CAN bus interface
  - Custom design according to the racing vehicle's carbon-fiber monocoque



- implementation in the electronic control unit (dSpace Scalexio/MicroAutoBox) of the following algorithms:

  - perception
  - trajectory planning
  - robust positioning
  - control

- functional testing and safety integration of braking and steering systems with the Remote Emergency System

- integration and testing of the braking and steering actuation systems in the vehicle

- continous experimental validation of the perception algorithms in the structured environment

- autonomous vehicle test in the structured environment

List of patents and published papers

PATENTS

1. Tonoli, A.; Amati, N.; Bonfitto, A.; **Feraco, S.**; Monti, F. ''Unità di propulsione con batteria per veicolo e relativo metodo per stimare lo stato di carica'' (Domanda di Brevetto Italiano n. 102019000006987, 17/05/2019) – undergoing PCT application

PAPERS

1. Bonfitto, A., **Feraco, S.**, Tonoli, A., Amati, N., & Monti, F. (2019). "Estimation Accuracy and Computational Cost Analysis of Artificial Neural Networks for State of Charge Estimation in Lithium Batteries." *Batteries*, *5*(2), 47.
2. Bonfitto, A., Tonoli, A., **Feraco, S**., Zenerino, E. C., & Galluzzi, R. (2019). "Pattern recognition neural classifier for fall detection in rock climbing." *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology*, 1754337119850927.
3. Bonfitto, A., **Feraco, S**., Tonoli, A., & Amati, N. (2019). "Combined regression and classification artificial neural networks for sideslip angle estimation and road condition identification." *Vehicle System Dynamics*, 1-22.
4. Bonfitto, A., Ezemobi, E., Amati, N., **Feraco, S.**, Tonoli, A., & Hegde, S. (2019, July). "State of Health Estimation of Lithium Batteries for Automotive Applications with Artificial Neural Networks." In *2019 AEIT International Conference of Electrical and Electronic Technologies for Automotive (AEIT AUTOMOTIVE)* (pp. 1-5). IEEE.
5. Bonfitto, A., **Feraco, S.**, Amati, N., & Tonoli, A. (2019, August). Virtual Sensing in High-Performance Vehicles With Artificial Intelligence. In *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference* (Vol. 59216, p. V003T01A005). American Society of Mechanical Engineers.
6. **Feraco, S.**, Bonfitto, A., Amati, N., & Tonoli, A. (2019, August). Combined Lane Keeping and Longitudinal Speed Control for Autonomous Driving. In *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference* (Vol. 59216, p. V003T01A018). American Society of Mechanical Engineers.
7. Galluzzi, R., **Feraco, S.**, Zenerino, E. C., Tonoli, A., Bonfitto, A., & Hegde, S. (2020). Fatigue monitoring of climbing ropes. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology*, 1754337120905674.
8. **Feraco S.**, Bonfitto, A., Amati, N., Tonoli A. (2020, August). "A Lidar-based Clustering Technique for Obstacles and Lane Boundaries Detection in Assisted and Autonomous Driving". In Proceedings of the ASME 2020 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference (IDETC-CIE 2020), 22nd International Conference on Advanced Vehicle Technologies (AVT).
9. **Feraco S.**, Bonfitto, A., Amati, N., Tonoli A. (2020, August). "Optimal Trajectory Generation Using an Improved Probabilistic Road Map Algorithm for Autonomous Driving". In Proceedings of the ASME 2020 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference (IDETC-CIE 2020), 22nd International Conference on Advanced Vehicle Technologies (AVT).
10. Khan I., **Feraco, S.**, Bonfitto, A., Amati N. (2020, August). "A Model Predictive Control Strategy for Lateral and Longitudinal Dynamics in Autonomous Driving". In Proceedings of the ASME 2020 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference (IDETC-CIE 2020), 22nd International Conference on Advanced Vehicle Technologies (AVT).
11. Filomeno G., **Feraco, S.** (2020), "Economic, Technical and Environmental Aspects of Recycling Lithium Batteries: A Literature Review". Global Journal of Researches in Engineering: B – Automotive Engineering, Volume XX, Issue 1, 1-9.
12. **Feraco S.**, Luciani S., Bonfitto, A., Amati, N., Tonoli A. (2020, November). "A local trajectory planning and control method for autonomous vehicles based on the RRT algorithm". 2020 AEIT International Conference of Electrical and Electronic Technologies for Automotive - Track 3 Advanced driver assistance systems and autonomous driving, safety and connectivity. IEEE. (accepted for publication)
13. Bonfitto A., **Feraco S.**, Rossini M., Carlomagno F. (2020) "Fuzzy Logic Method for the Speed Estimation in All-Wheel Drive Electric Racing Vehicles", Communications - Scientific letters of the University of Zilina. (accepted for publication)

Thank you for your attention!

QUESTIONS

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