Workshop AI @ CARS

AI-powered assisted and autonomous driving

Stefano Feraco

PhD Student – XXXIV cycle

About me

Stefano Feraco

PhD Student – XXXIV cycle
(2018-2021)
Mechanical Engineering

B.Sc. in Electrical Engineering (2016) @ PoliTO

M.Sc in Mechatronic Engineering (2017) @ PoliTO

Main research area

<u>Design, modeling and control of Autonomous vehicles</u>

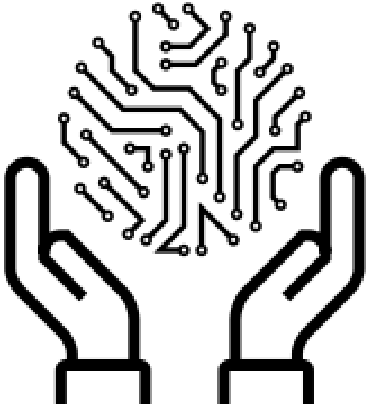
SIDE PROJECTS

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

List of contents

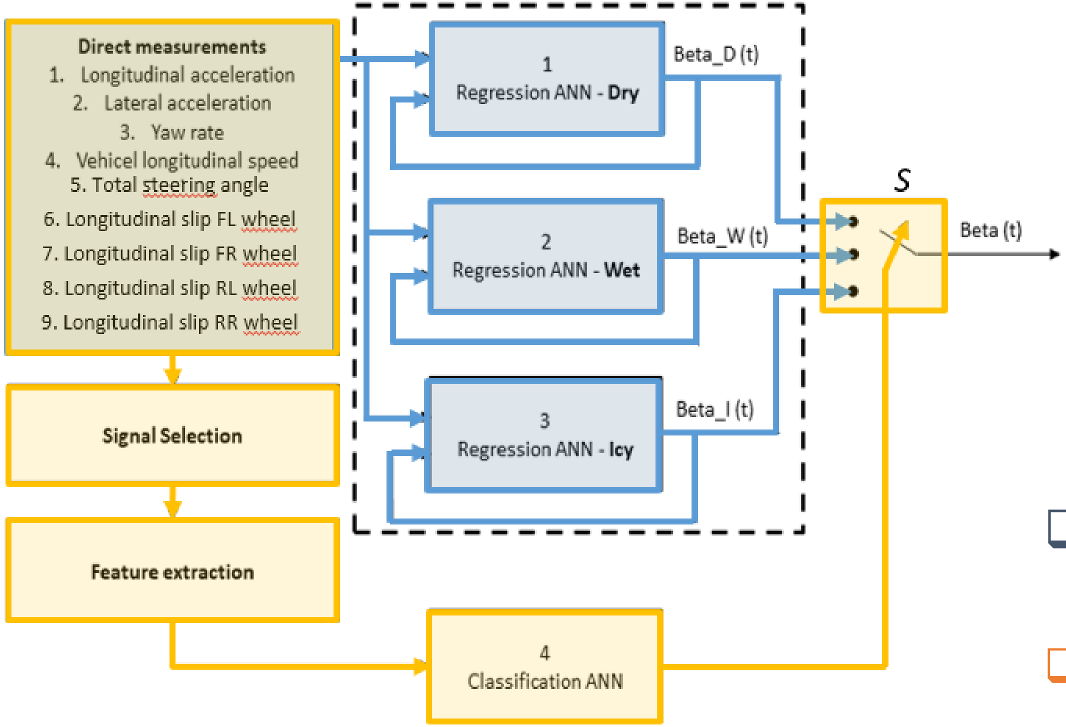
- **Assisted driving: virtual sensing**
  - Sideslip angle estimation and road condition identification with ANNs
  - Longitudinal speed estimation with ANNs
  - Longitudinal speed estimation with Fuzzy Logic

- **Autonomous driving: perception, localization and planning**
  - Autonomous system layout
  - Perception pipeline with LiDAR and stereocamera
  - LiDAR-based perception
  - Stereocamera-based perception
  - Trajectory planning - RRT algorithm
  - Trajectory planning with RRT – Results



Virtual sensing

Sideslip angle estimation and road condition identification with ANNs

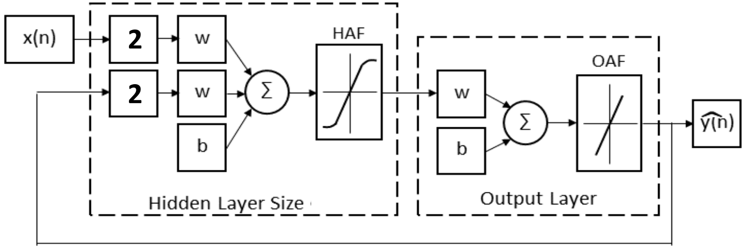


- ❑ 1) **Sideslip Angle Estimation**
  Regression ANNs
- ❑ 2) **Road Condition Identification**
  Classification ANN

Sideslip angle estimation and road condition identification with ANNs

Regression tasks – Sideslip angle estimation

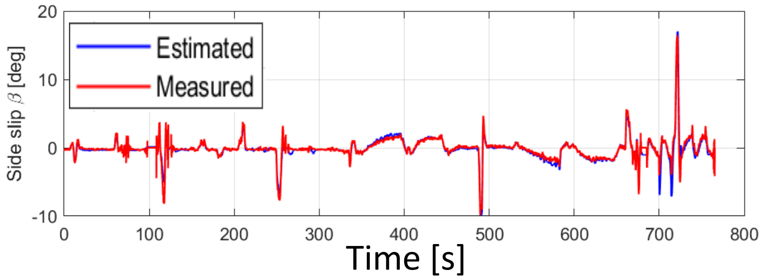
NARX ANN



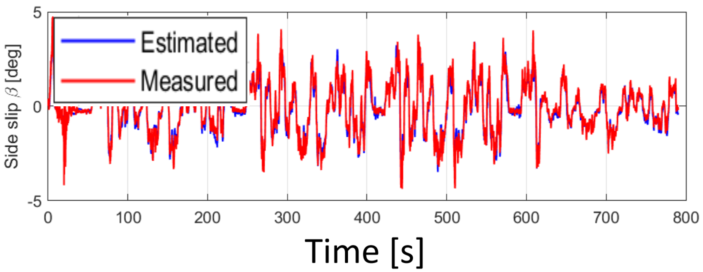
Input Delays	2
Feedback Delays	2
Hidden Layer Size	20 neurons
TrainFcn	trainbr

Average Relative Error
< 2%

TEST – Constant a_y / Constant Steer / Throttle Ramp



TEST – Racing / ESC off / Handling Lap

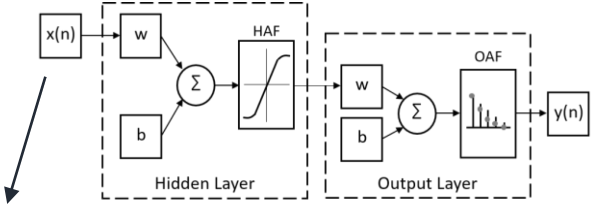


Sideslip angle estimation and road condition identification with ANNs

Classification tasks - Road condition identification

Pattern recognition neural classifier

- The sampling rate is 100 Hz.
- The classifier processes the predictors stacked in a *buffer* containing the acquisitions of the last 2 s. *(features extraction)*
- This buffer is emptied and refilled with a frequency of 10Hz, that, consequently, is the updating rate of the output.



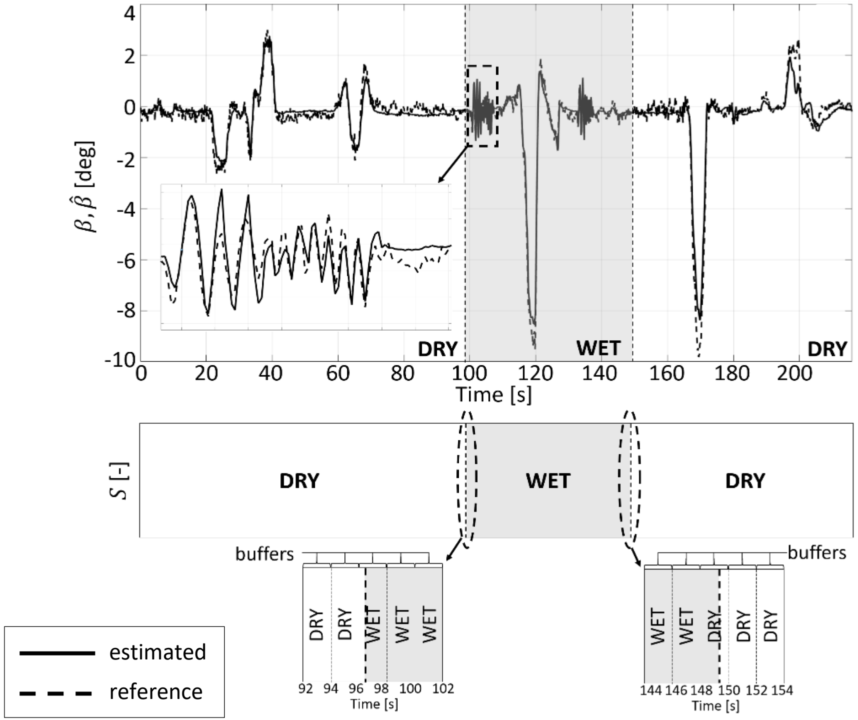
output $\hat{y}$(n)
road condition
(DRY, WET, ICY)

input x(n)
64 features extracted from:
- Long.Acceleration; - Lat. Acceleration; - Yaw Rate; - Long. Velocity of the wheels

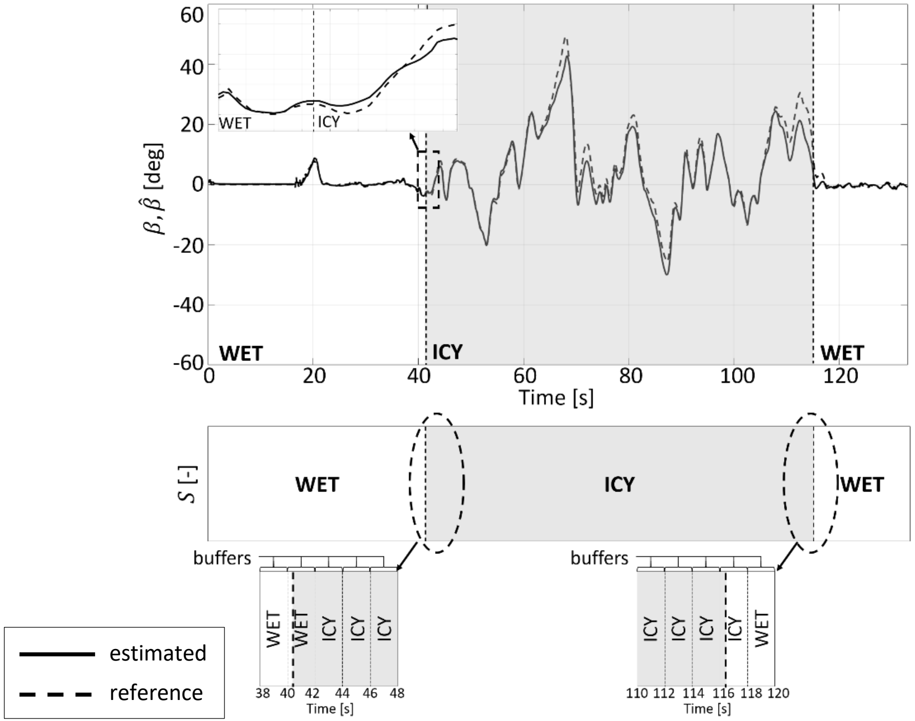
Classified road condition \ Actual road condition	Dry	Wet	Icy	
Dry	**37805** CL: 35.35%	**151** CL: 0.14%	**120** CL: 0.11%	
Wet	**114** CL: 0.11%	**25085** CL: 23.46%	**32** CL: 0.03%	
Icy	**104** CL: 0.1%	**10** CL: 0.01%	**43523** CL: 40.7%	
	N_D: **38023** α_{C_D} 99.43 %	N_W: **25246** α_{C_W} 99.36 %	N_I: **43675** α_{C_I} 99.65 %	N_{TOT}: **106944** $\alpha_{C_{TOT}}$ 99.5%

Sideslip angle estimation and road condition identification with ANNs

Transient from DRY to WET asphalt and viceversa



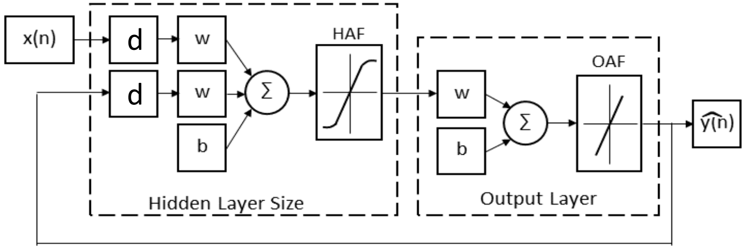
Transient from WET to ICY asphalt and viceversa



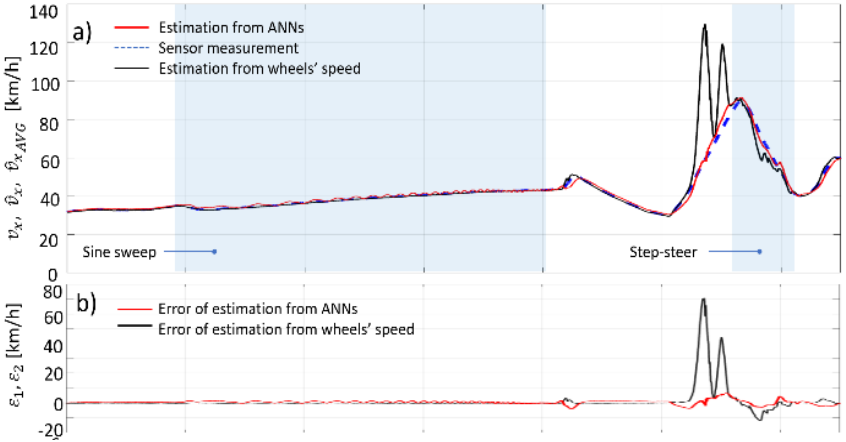
Longitudinal speed estimation with ANNs

Regression tasks – Longitudinal speed estimation

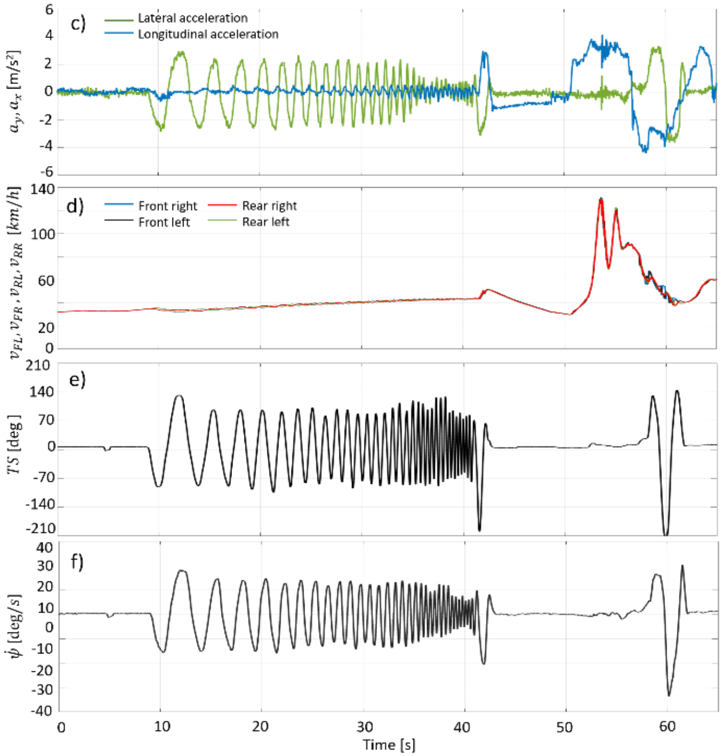
NARX ANN



RESULT



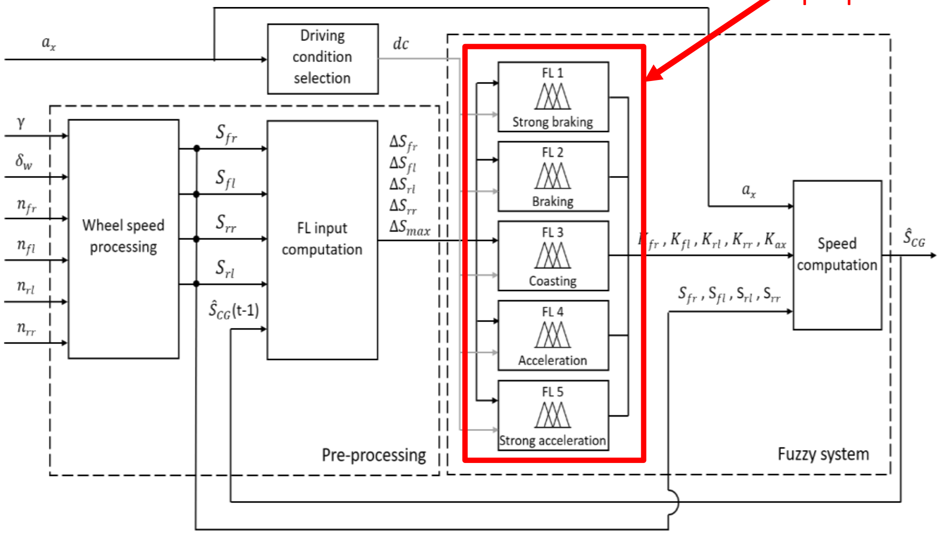
INPUT SIGNALS



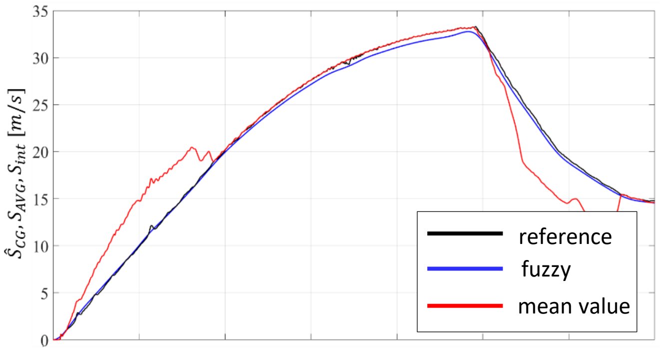
Longitudinal speed estimation with Fuzzy Logic

Fuzzy architecture
exploits the lateral and longitudinal acceleration information to avoid errors caused by a possible locking or spinning phase of the tyres

each driving condition has its proper fuzzy system



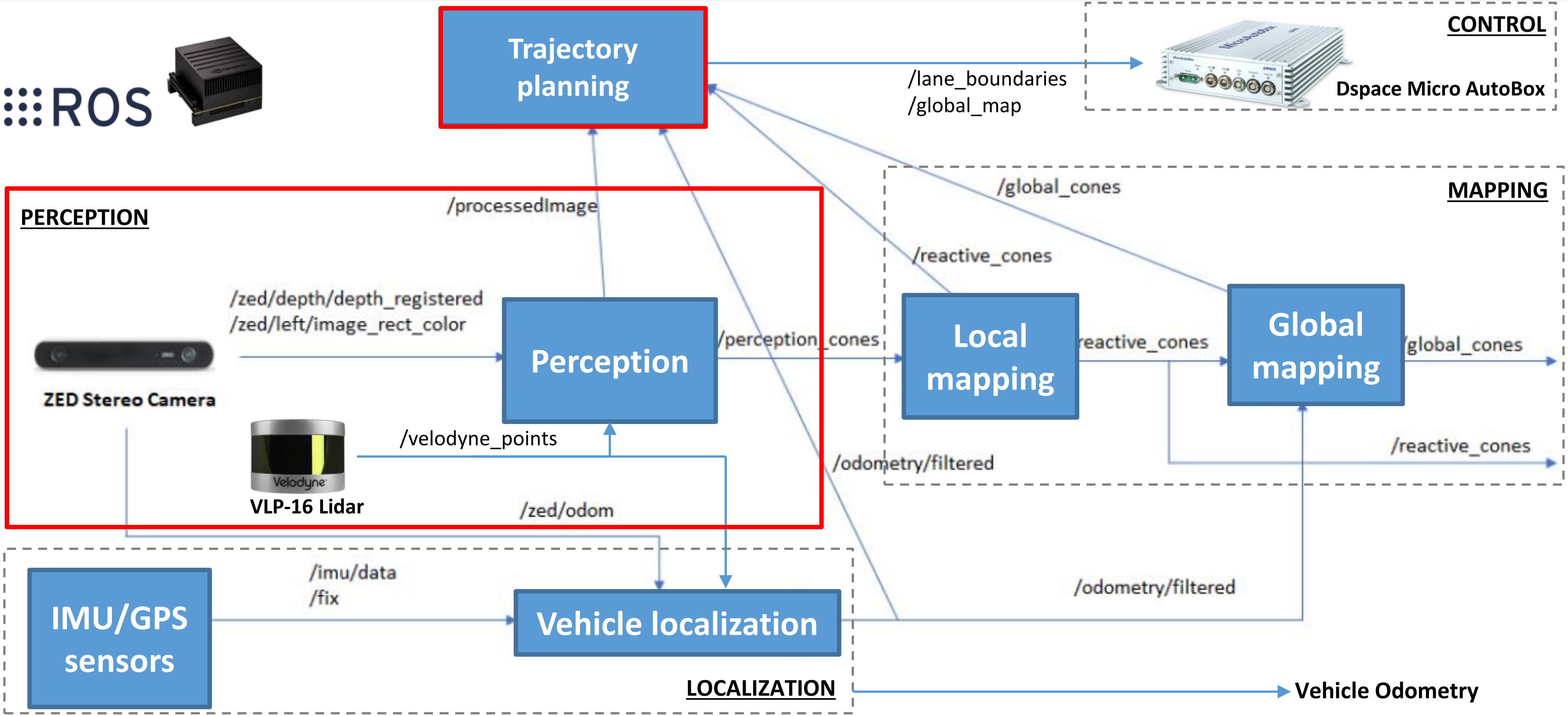
RESULT



Vehicle speed is accurately estimated also in the case of spinning or skidding

Autonomous Driving

Autonomous system layout

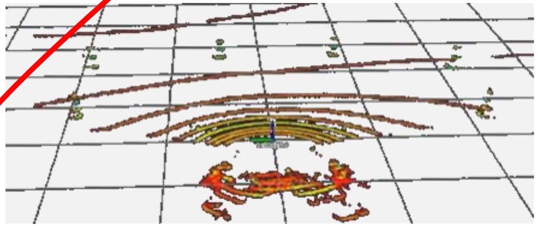


LiDAR-based perception

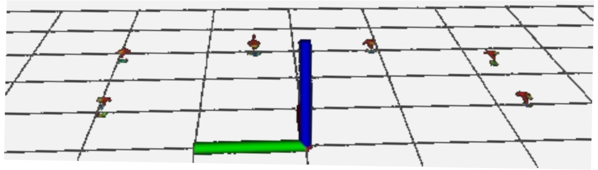
❑ Method

- Semantic segmentation of LiDAR point-clouds
- Ground removal is performed with an iterative intelligent algorithm

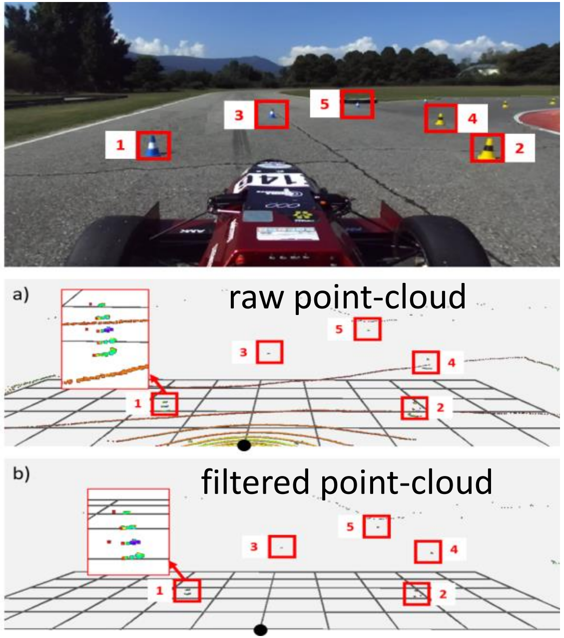
raw point-cloud



filtered point-cloud

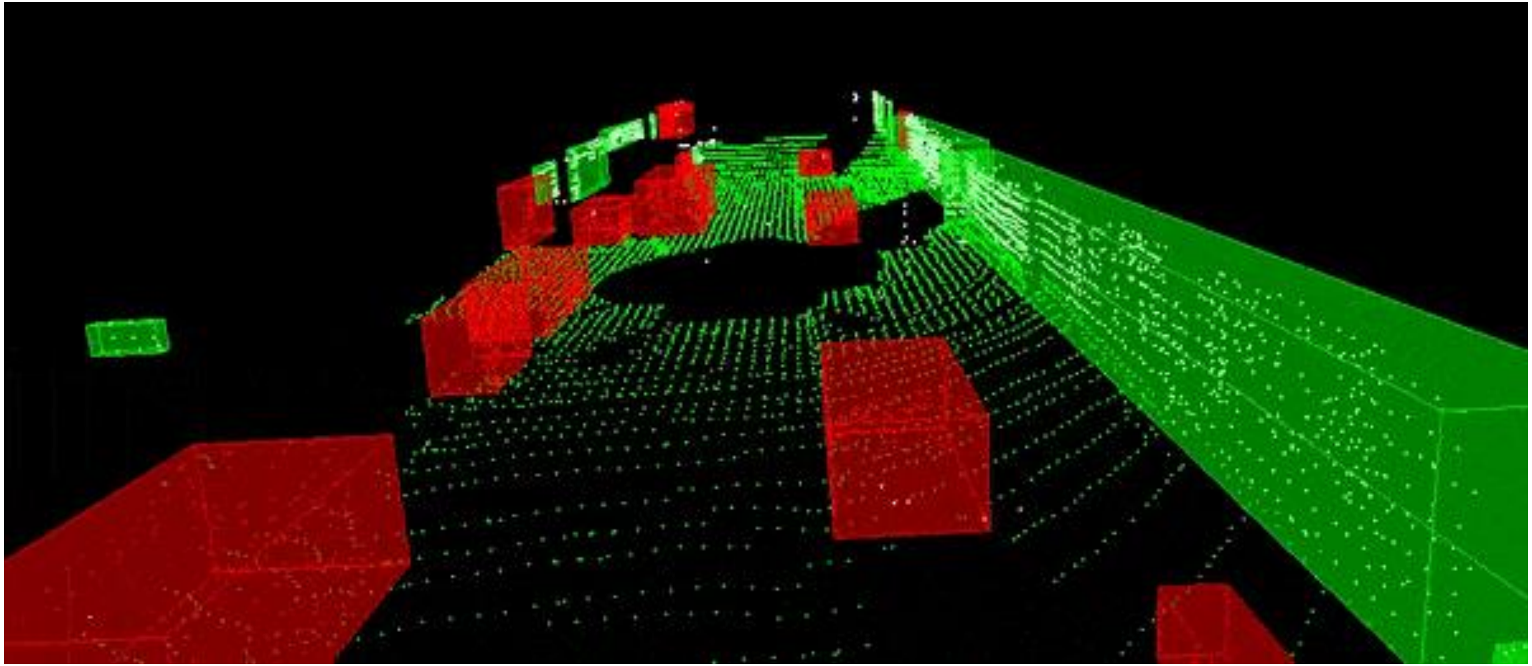


RESULT



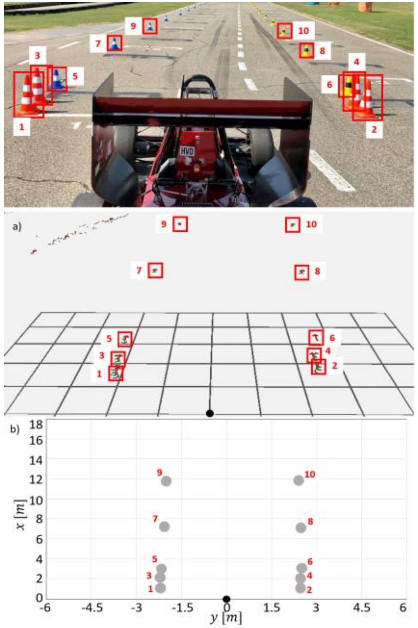
LiDAR-based perception

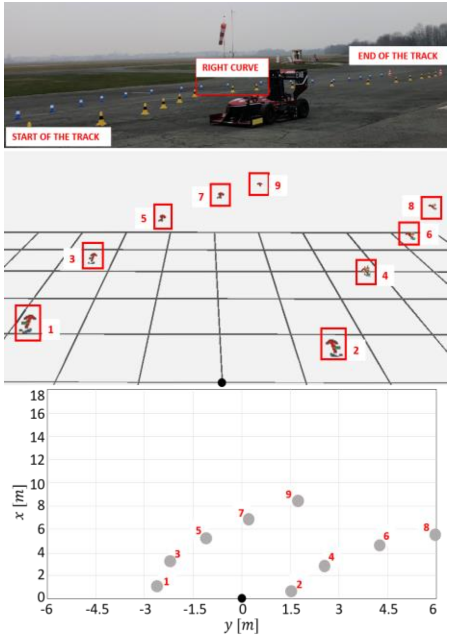
- Through an intelligent iterative procedure, the ground plane is identified and removed.
  Seed points are iteratively generated and added to the ground plane set of points.
  Clusters (in red) can be identified with any distance-based classification algorithm



LiDAR-based perception

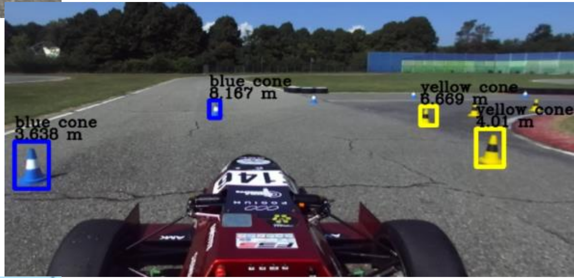
- **Results**
  - Clustering of points is performed to detect traffic cones in real-time
  - A 2D local map is created



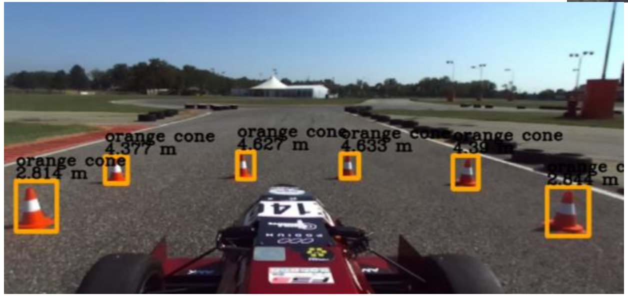


Stereocamera-based perception

❑ Method



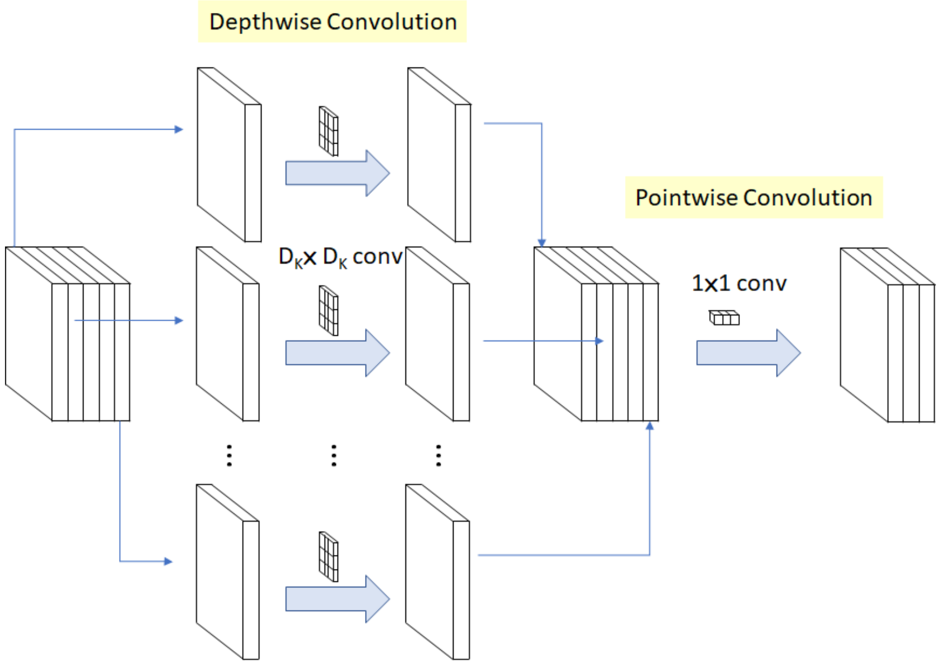
- Convolutional neural networks
- Based on single shot detector MobileNetV1



SSD MobileNetV1 – classical structure

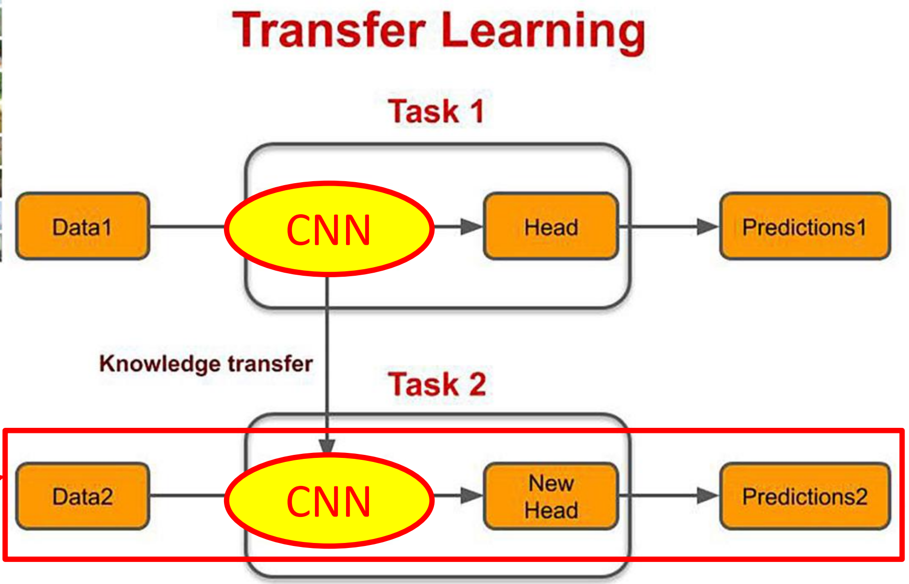
Table 1. MobileNet Body Architecture

Type / Stride	Filter Shape	Input Size
Conv / s2	3 × 3 × 3 × 32	224 × 224 × 3
Conv dw / s1	3 × 3 × 32 dw	112 × 112 × 32
Conv / s1	1 × 1 × 32 × 64	112 × 112 × 32
Conv dw / s2	3 × 3 × 64 dw	112 × 112 × 64
Conv / s1	1 × 1 × 64 × 128	56 × 56 × 64
Conv dw / s1	3 × 3 × 128 dw	56 × 56 × 128
Conv / s1	1 × 1 × 128 × 128	56 × 56 × 128
Conv dw / s2	3 × 3 × 128 dw	56 × 56 × 128
Conv / s1	1 × 1 × 128 × 256	28 × 28 × 128
Conv dw / s1	3 × 3 × 256 dw	28 × 28 × 256
Conv / s1	1 × 1 × 256 × 256	28 × 28 × 256
Conv dw / s2	3 × 3 × 256 dw	28 × 28 × 256
Conv / s1	1 × 1 × 256 × 512	14 × 14 × 256
5× Conv dw / s1	3 × 3 × 512 dw	14 × 14 × 512
5× Conv / s1	1 × 1 × 512 × 512	14 × 14 × 512
Conv dw / s2	3 × 3 × 512 dw	14 × 14 × 512
Conv / s1	1 × 1 × 512 × 1024	7 × 7 × 512
Conv dw / s2	3 × 3 × 1024 dw	7 × 7 × 1024
Conv / s1	1 × 1 × 1024 × 1024	7 × 7 × 1024
Avg Pool / s1	Pool 7 × 7	7 × 7 × 1024
FC / s1	1024 × 1000	1 × 1 × 1024
Softmax / s1	Classifier	1 × 1 × 1000



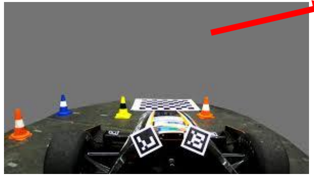
Stereocamera-based perception

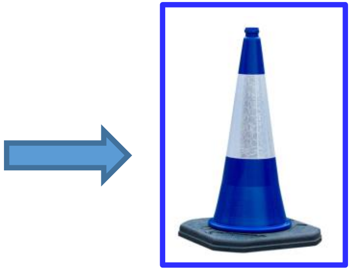
- SSD MobileNetV1 – transfer learning



It's a horse!

Traffic cones set of images is used for transfer learning



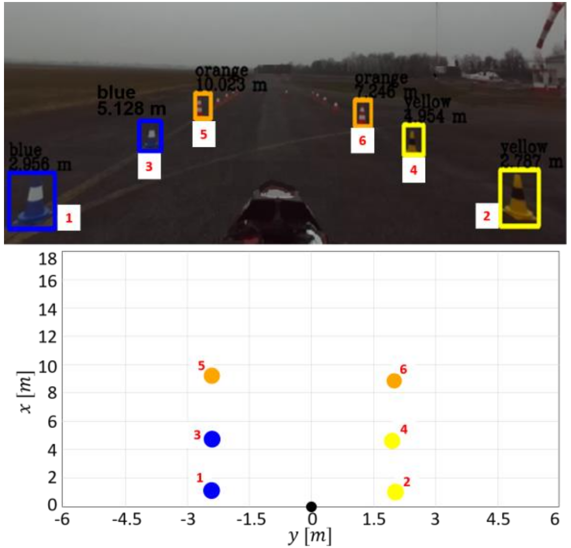


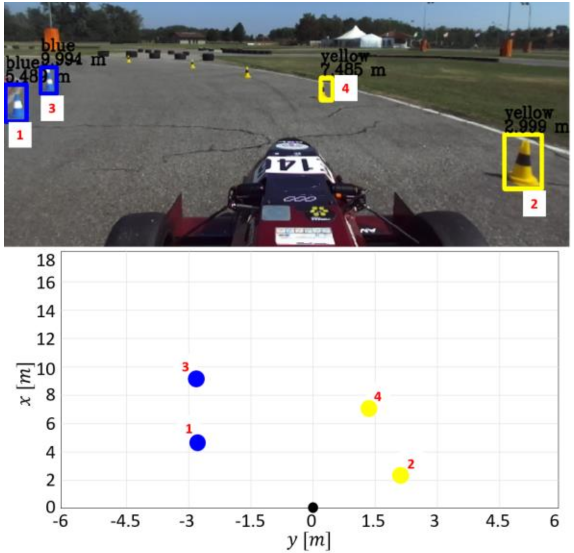
It's a blue cone!

Stereocamera-based perception

❑ Result

- Depth-map matching with stereoimage is performed to estimate the distance of the bounding boxes
- A 2D local map is created



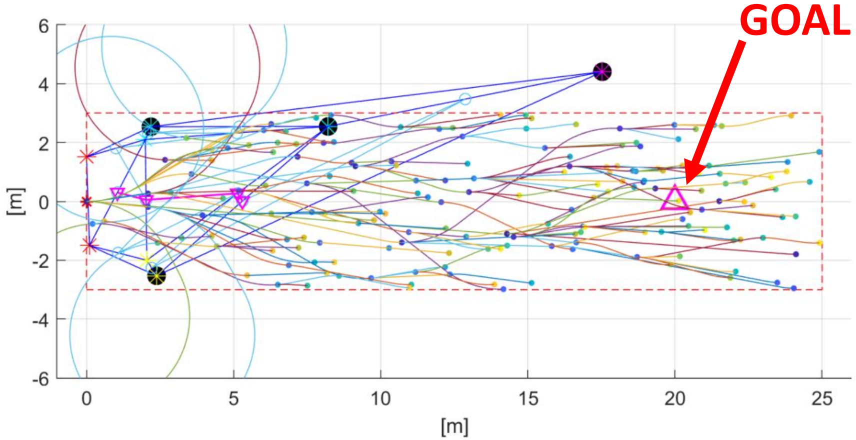


Trajectory planning – RRT algorithm

In cooperation with PhD student: Sara Luciani

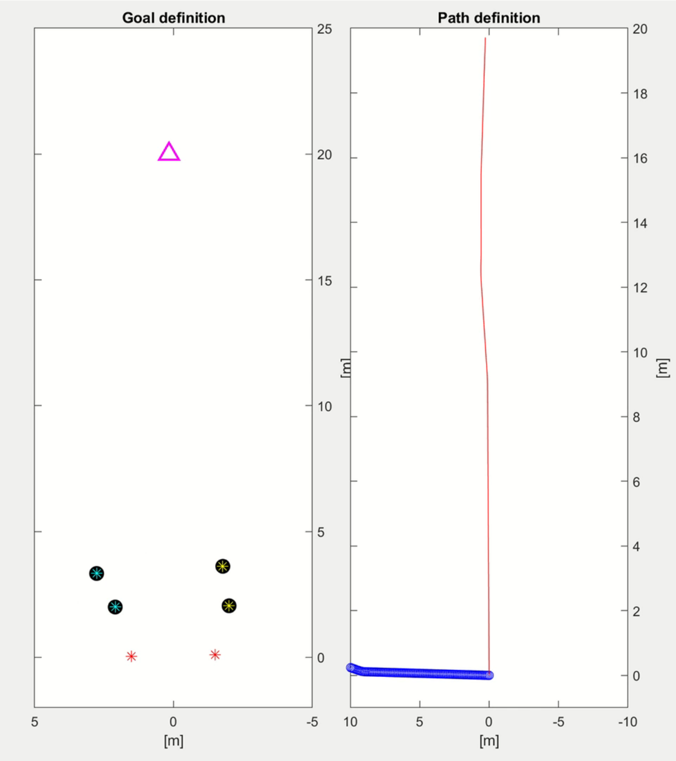
On the basis of the goal calculated for the specific frame (frequency of 10 [Hz]), a **search tree** with **Rapidly-exploring Random Tree** using **Dubins curves** is built.
To choose the path that the vehicle has to follow, a reverse intelligent process is carried out:

1) the closest node of the search tree to the *goal* is found;
2) the path is travelled from this vertex till the *origin*, where the vehicle is located ($[x, y, \theta] = [0,0,0]$).

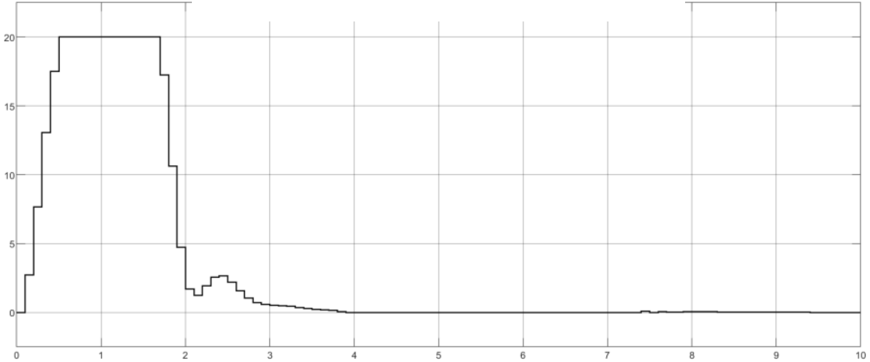


Trajectory planning with RRT – Results on a straight road

In cooperation with PhD student: Sara Luciani



Acceleration command



Steering command

Future work and research plan

- functional testing and safety integration of investigated systems
- software integration of the systems in the racing vehicle
- continous experimental validation of the perception algorithms in the structured environment
- autonomous vehicle extensive testing in the structured environment
- an autonomous vehicle Student Team will be built as an outcome of the presented results

Shortlist of my relevant patents and papers in CARS @ PoliTo

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., **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.
3. 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.
4. 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.
5. **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.
6. **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).
7. **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).
8. 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).
9. **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)
10. 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 – online on April 2021)
11. **S. Feraco**, S. Luciani, A. Bonfitto, N. Amati and A. Tonoli, "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 (AEIT AUTOMOTIVE), Torino, Italy, 2020, pp. 1-6.
12. Bonfitto A., **Feraco S.** (2020) "A data-driven method for speed estimation", Communications - Scientific letters of the University of Zilina. (accepted for publication – online on April 2021)
13. **Feraco S.**, Bonfitto, A., Amati, N., Tonoli, A. (2021) "Redundant object detection method for autonomous vehicles in structured environments", International Journal of Vehicle Technology. (under peer-review)
14. **Feraco S.**, Anselma, P. G., Bonfitto, A., Kollmeyer, P. (2021) "Robust data-driven battery state of charge estimation for hybrid electric vehicles", Jorunal of Power Sources. (under peer-review)

Thank you for your attention