PhD in Information Technology and Electrical Engineering

Università degli Studi di Napoli Federico II

PhD Student: Angelo Coppola

XXXIV Cycle

Training and Research Activities Report – Third Year

Tutor: Stefania Santini

1. Information

    a. Angelo Coppola, MS degree in Hydraulic and Transportation Systems Engineering – University of Naples Federico II.

    b. XXXIV Cycle- ITEE – Università di Napoli Federico II.

    c. Fellowship type: “Borsa POR”.

    d. Tutor: Prof.ssa Stefania Santini.

    e. Co-Tutor: Luisa Andreone and Anita Fiorentino, Stellantis group (ex FCA group)

2. Study and Training activities

    a. Ad Hoc Courses

        - “From observability to privacy and security in discrete event systems (5 CFU).
          Lecturer: Prof. Gianmaria De Tommasi
          14/12/2020-15/12/2020-16/12/2020-17/12/2020-18/12/2020-21/12/2020

    b. Ph.D. School

        - “Short Course on DYNAMIC TRAFFIC FLOW MODELLING AND CONTROL” (3 CFU).
          Lecturer: Prof. Markos Papageorgiou
          8 - 19 February 2021

3. Research activity

    a. Title: “C-ITS services and advanced vehicle control for complex traffic scenarios”

    b. Study: Smart and autonomous system, connected vehicles, virtual vehicle simulation platform.

    c. Research description

The transformation towards “Smart Roads” is underway in full harmony with the processes of governing and managing innovation in the sector in Europe, with reference to the European C-ITS Platform (Cooperative Intelligent Transport Systems; C-ITS), to the GEAR 2030 initiative and to the Smart Road Decree signed by the Italian Government in March 2018. The process involves the development and exploitation of key technologies for enabling innovative and automated driving functions and applications, as well as the design of demonstration scenarios in which automated driving functions are tested in various use cases. The main idea is to improve road safety and traffic flow, and to reduce congestion, fuel consumption and pollutant

emissions.
New C-ITS (connected and fully automated) mobility services can also contribute to reducing overall traffic, making cities and human settlements safe, resilient, sustainable, and decrease the number of deaths and injuries caused by road accidents. An open challenge is related to the introduction of automated vehicles in existing traffic poses specific and new problems in terms of reliability and effectiveness, concerning interactions with other vehicles and/or other actors of the traffic scenario, such as pedestrians, public vehicles or cyclists. Furthermore, automated guidance systems must be appropriately designed to be resilient both to the uncertainties of V2X communication, to guarantee enough reliability and robustness in every traffic situation in the real world.
In this framework, my study focuses on the develop of cooperative strategies for cooperative vehicles, based on both onboard sensors and V2X communication, and test them in complex traffic contexts with high interaction between vehicles.
To develop these strategies, methodologies for cooperative and distributed control of multi-agent systems, advanced techniques for the control of cyber-physical systems and algorithms of Sensor Fusion were widely used.
The development of such cooperative strategies needs for testing and validation, due to a wide range of driving situations in which vehicles can be in.

During the third year, the develop of a light-weighted and open Virtual Simulation Platform for mixed traffic (called MiTraS, i.e., Mixed Traffic Simulator), aiming to easily test and validate C-ITS strategies in mixed traffic, has been continued. The MiTraS platform is based on the integration of SUMO and Matlab/Simulink, so to have a realistic representation of Vehicle Dynamics and Surrounding Road Environment, and to quantify the impacts, benefits and costs of connected and automated vehicles driving systems in urban mixed traffic flow (connected human-driven and autonomous). Specifically, Matlab/Simulink allows to manage Vehicle Dynamics, Sensors and Control Logics, and to create a simplified 3D road environment, while SUMO is used to recreate realistic road traffic conditions. The main advantages of such a tool are: 1) light-weighted tool, so no powerful hardware is needed to perform simulations; 2) low cost because no commercial software is required; 3) easily adaptable to developer's needs.
The proposed virtual simulation platform has been used to numerically analyse the control strategies for each of the addressed road traffic issues.

1. One of the most critical challenges for the development of reliable and robust and C-ITS service, is to define an effective testing methodology. In this perspective, an enhanced testing approach of the so-called Green Light Optimal Speed Advisory (GLOSA) service, has been proposed. Specifically, it can be used to cover several aspects which, in the existing technical literature, are: i) not considered (traffic signal phase condition); ii) rarely considered (electric engine); iii) considered in a non-integrated way (traffic condition, TLS cycle duration, communication distance and minimum speed). Indeed, the considered factors pertain to different subsystems of the mobility environment (network and vehicles), and the proposed testing framework allows an equally detailed simulation of all, thus enhancing the accuracy of the results. To show the validity of the proposed approach, the exemplary case of one controlled vehicle, equipped with a GLOSA system, travelling along a single route through a city centre including many TLSs, has been considered. Moreover, the simulation analysis deals with different levels of considered factors, assessed through Key Performance Indicators (KPIs) related to mobility and environmental indicators.

2. A cooperative fully distributed control protocol for CAVs is proposed to deal with the open challenge of decentralized crossing at unsignalized intersections for mixed traffic flows, composed of Connected Human-driven Vehicles (CHVs) and CAVs. The proposed control action augments the classical ACC action with an additional networked protocol exploiting V2V information for the cooperative evaluation of the Time-to Intersection of all incoming vehicles within the communication range. This further collaborative action automatically adapts the CAVs motion at the intersection,

avoiding collisions with other cars and reducing stop and waiting times. The analysis is carried out for an exemplary two-lane four-way unsignalized road intersection considering several traffic demands levels, several CAVs penetration rates, and the presence of variable delays affecting the wireless communication network. The extensive simulation analysis confirms how the inclusion of CAVs, equipped with the proposed control algorithm, within the mixed traffic low improves both safety and mobility performances of the intersection.

3. Typically, technical literature neglects cornering effect in the computation of the energy consumption of electric vehicles. However, when travelling along curved urban road, it has a relevant impact on consumption cannot be overlooked. Moreover, in addition to the energy saving problem, in real traffic scenarios, vehicles have also to accomplish different driving tasks at the same time such as, for example, avoiding collisions with obstacles while tracking a path along a curved road. To deal with it, a double-layer control architecture combining the classical Adaptive Cruise Control with a Nonlinear Model Predictive Control. This latter is designed so to drive the autonomous vehicle along a predefined path while guaranteeing the maintenance of a safe distance w.r.t. a predecessor vehicle ahead and ensuring energy-saving consumption. The appraised control-oriented design model is non-linear and the energy consumption one explicitly accounts for the cornering effects.

4. Typically, technical literature considers linear dynamical system to describe the vehicle dynamics and do not consider for the model nonlinearities induced by vehicle powertrain system (e.g., engine, driveline, and aerodynamic drag). Vehicle dynamics parameters are also affected by uncertainties since there are a lot of mismatches between the real plant and the model, due to the environmental disturbances, parameter variations, and neglected dynamics. Another issue in the cooperative driving application are the platooning manoeuvres (i.e., create, merge and disengaged platoons) since vehicles must be able to join or leave a platoon at any time. Indeed, during such manoeuvres, some communication links among the vehicles within the platoon can be created and/or disrupted. This implies a switching of the communication topology, and the designed platoon control strategy has also to cope with such time-varying structure of the communication network. To overcome all the issues, a novel robust distributed PI-based control strategy which ensures that all vehicles within the platoon track the leader behaviour while coping with both the time-varying structure of the communication network and the presence of unknown uncertainties acting on their dynamics has been proposed. The control strategy weights the vehicle state information via proportional actions that are augmented with an additional integral action on the position state information so to improve the steady-state and robustness performances.

5. An emerging challenge for platoon applications, besides the leader-tracking one, is the energy-saving. Electric Vehicles are considered the most promising and viable near-term technology to reduce the exploitation of fossil fuels and resulting greenhouse gas emissions produced by conventional vehicles. Although sustainability and environmental benefits may have a major influence on their adoption, the maximization of electric vehicles range autonomy is a crucial aspect for their massive market deployment. In this framework, a cooperative driving control strategy able to let electric vehicles move as a convoy while keeping a variable energy-oriented inter-vehicle distance between adjacent vehicles, able to guarantee air-drag reduction, energy saving and collision avoidance simultaneously, has been proposed. To this aim, by exploiting a distance-dependent air drag coefficient formulation, a novel distributed nonlinear model predictive control (DNMPC) has been proposed, where the cost function was designed to ensure leader tracking performances, as well as to optimise the inter-vehicle distance with the aim of reducing energy consumption. Extensive simulation analyses, involving a comparative analysis with respect to the classical constant time headway (CTG) spacing policy, were performed to confirm the capability of the DNMPC in guaranteeing energy saving.

6. Most of the existing technical literature solve the platooning problem asymptotically, without ensuring that the consensus could be achieved in a finite settling time. To this aim, the problem of guaranteeing the leader-tracking for heterogeneous vehicles platoons in a fixed time despite the presence of external disturbances has been addressed. To solve this problem, by exploiting the integral sliding mode (ISM) approach and the Lyapunov theory, a distributed control strategy able to ensure the leader-tracking in a finite settling time which is independent from any vehicles initial conditions has been proposed. The simulation analysis has been carried out in two different driving scenarios to confirm the effectiveness of the theoretical derivation.

d. Collaborations

- Research Group of Prof. Gennaro Nicola Bifulco (DICEA, Università di Napoli Federico II)
- Stellanti N.V. group (ex-Fiat Chrysler Automobiles group, FCA)
- Prof. Savvas G. Loizou, Associate Professor at Cyprus University of Technology, Department of Mechanical Engineering and Material Science and Engineering (Cyprus)

4. Products

a. Publications

i. **Published:** Coppola, A., Di Costanzo, L., Pariota, L., Santini, S., & Bifulco, G. N. (2022). An Integrated Simulation Environment to test the effectiveness of GLOSA services under different working conditions. Transportation Research Part C: Emerging Technologies, 134, 103455
ii. **Published:** Caiazzo, B., Coppola, A., Petrillo, A., & Santini, S. (2021). Distributed nonlinear model predictive control for connected autonomous electric vehicles platoon with distance-dependent air drag formulation. Energies, 14(16), 5122.
iii. **Published:** Coppola, A., Petrillo, A., Rizzo, R., & Santini, S. (2021, October). Adaptive Cruise Control for Autonomous Electric Vehicles based on Q-learning algorithm. In 2021 AEIT International Annual Conference (AEIT) (pp. 1-6).
iv. **Published**: Bifulco, G. N., Coppola, A., Loizou, S. G., Petrillo, A., & Santini, S. (2021, September). Combined Energy-oriented Path Following and Collision Avoidance approach for Autonomous Electric Vehicles via Nonlinear Model Predictive Control. In 2021 IEEE International Conference on Environment and Electrical Engineering and 2021 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe) (pp. 1-6). IEEE. DOI: 10.1109/EEEIC/ICPSEurope51590.2021.9584501
v. **Published:** Tesone, A., Coppola, A., Di Costanzo, L., Pariota, L., & Bifulco, G. N. (2021, September). Route guidance systems based on the macroscopic fundamental diagram concept: a Simulation-Based Case Study in the city of Portici. In 2021 IEEE International Conference on Environment and Electrical Engineering and 2021 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe) (pp. 1-6). IEEE. DOI: 10.1109/EEEIC/ICPSEurope51590.2021.9584783
vi. **Published:** Coppola, A., Lui, D. G., Petrillo, A., & Santini, S. (2021, June). Distributed Fixed-Time Leader-Tracking Control for Heterogeneous Uncertain Autonomous Connected Vehicles Platoons. In 2021 29th Mediterranean Conference on Control and Automation (MED) (pp. 554-559). IEEE. DOI: 10.1109/MED51440.2021.9480345
vii. **Published:** Caiazzo, B., Coppola, A., Petrillo, A., & Santini, S. (2021). Energy-Oriented Inter-Vehicle Distance Optimization for Heterogeneous E-Platoons. In Optimization and Data Science: Trends and Applications (pp. 113-125). Springer, Cham.

5. Conferences and Seminars

   a. Details

      - 2021 IEEE International Conference on Environment and Electrical Engineering and 2021 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe)
        - 2 conference articles;
      - 2021 29th Mediterranean Conference on Control and Automation (MED)
        - 1 conference article;
      - 2021 AEIT International Annual Conference (AEIT)
        - 1 conference article;

   b. Presentations made

      - 2021 IEEE International Conference on Environment and Electrical Engineering and 2021 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe)
      - 2021 29th Mediterranean Conference on Control and Automation (MED)
      - 2021 AEIT International Annual Conference (AEIT)

6. Activity abroad

   a. Details: study of cooperative control strategy for autonomous vehicle, able to share information via V2V, in complex road traffic scenarios.
   b. Dates: 01/02/2021 – 30/04/2021;
   c. Places: via telematic mode (smart working);
   d. Partner: Mechanical and Materials Science and Engineering, Cyprus University of Technology (Dorothea Bldg 507, 45 Kitiou Kyprianou Str., Limassol 3041, Cyprus);
   e. Contact: Prof. Savvas G. Loizou, Assistant Professor of Automatic Control, e-mail: savvas.loizou@cut.ac.cy.

7. Tutorship
   a. supplementary teaching and subsidiary teaching for a total of 20 hours as part of the FIRST YEAR TECHNOLOGICAL ACTIVITIES course - Bachelor's Degree in Infrastructure and Services Engineering (no SSD, "Other Activities" type activity) in the A.Y.: 2021 / 2022;
   b. supplementary teaching and subsidiary teaching for a total of 20 hours as part of the TESTING AND VALIDATION OF AUTOMATED ROAD VEHICLES course - "Autonomous Vehicle" Master's Degree (SSD Icar/ 05) in the A.Y. 2021/2022.

The Table below summarizes the credits earned during the Ph.D. program.

	Credits year 1							Credits year 2							Credits year 3								
	1	2	3	4	5	6		1	2	3	4	5	6		1	2	3	4	5	6			
	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	**Summary**	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	**Summary**	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	**Summary**	**Total**	**Check**
Modules	2	3	3	0,8	6	3	**17,8**	1,6	3,3	2	7	6	0	**19,9**	0	5	0	0	0	0	**5**	**42,7**	**30-70**
Seminars	1,4	0,5	1	1,4	0	3,7	**8**	2,2	0	0,6	0,2	0	0	**3**	0	3	0	0	0	0	**3**	**14**	**10-30**
Research	6,6	6,5	6	7,8	4	3,3	**34,2**	6,2	6,7	7,4	2,8	4	10	**37,1**	10	2	10	10	10	10	**52**	**123,3**	**80-140**
	10	10	10	10	10	10	**60**	10	10	10	10	10	10	**60**	10	10	10	10	10	10	**60**	**180**	**180**

For the sake of completeness, the Table below summarizes the credits earned during the Ph.D. program considering the extension of three months.

	Credits year 1							Credits year 2							Credits year 3										
	1	2	3	4	5	6		1	2	3	4	5	6		1	2	3	4	5	6	7	8			
	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	**Summary**	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	**Summary**	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	**Summary**	**Total**	**Check**
Modules	2	3	3	0,8	6	3	**17,8**	1,6	3,3	2	7	6	0	**19,9**	0	5	0	0	0	0	0	0	**5**	**42,7**	**30-70**
Seminars	1,4	0,5	1	1,4	0	3,7	**8**	2,2	0	0,6	0,2	0	0	**3**	0	3	0	0	0	0	0	0	**3**	**14**	**10-30**
Research	6,6	6,5	6	7,8	4	3,3	**34,2**	6,2	6,7	7,4	2,8	4	10	**37,1**	10	2	10	10	10	10	10	10	**72**	**123,3**	**80-140**
	10	10	10	10	10	10	**60**	10	10	10	10	10	10	**60**	10	10	10	10	10	10	10	10	**80**	**200**	**180**