PhD THESIS

Title: Mesoscopic traffic control systems for Autonomous Vehicles

Laboratory: L2S (Laboratoire des Signaux et Systèmes), UMR 8506 Université Paris-Saclay, CNRS, CentraleSupélec, Laboratoire des Signaux et Systèmes, 91190, Gif-sur-Yvette, France.

Ph.D supervisor: **Silviu-Iulian NICULESCU** (silviu.niculescu@centralesupelec.fr)
Co-supervisor: **Alessio IOVINE** (alessio.iovine@centralesupelec.fr)

General information: 3 years, starting from Oct.-Nov. 2022
Application deadline: 23 May 2022
Funding: Paris-Saclay University
Keywords: Traffic control, Partial Differential Equations, String stability, Non-linear control, Machine-learning control based approach

DESCRIPTION OF THE THESIS:

Context

Disruptive technologies have paved the road for new types of traffic control systems. Two main approaches have been proposed in the literature:

- displacement of autonomous vehicles to reduce stop-and-go waves propagation and traffic oscillations via the concepts of String Stability, based on an Ordinary Differential Equations (ODEs) modeling describing the traffic flow from a microscopic point of view (every single vehicle-driver unit and the interactions with the others);
- traffic management through intelligent infrastructures imposing speed limitations according to traffic conditions, based on a Partial Differential Equation (PDE) modeling describing the traffic flow from a macroscopic point of view (mainly flow and density of the whole set of vehicles).

Recently, new methods targeting to exploit the interaction between the controlled vehicles and the surrounding flow can be used to modify the traffic density to improve congestion and reduce emissions. These methods are based on a mesoscopic approach, introducing macroscopic information in a microscopic framework for improving local control strategies. A state variable describing the macroscopic information in an aggregate formalism is defined. The necessity to investigate the matching between the macroscopic vision and the microscopic one rises to verify the mixed approach's compatibility.

Scientific work

The main idea of the proposed approach relies on considering a vehicular platoon both from the macroscopic and microscopic points of view and to investigate and quantify the relations between the two models. To this purpose, a coupled PDE-ODE model is of interest. The coupling of the ODE model with the PDE is generated by taking into account the impact of macroscopic variables for the microscopic model in the vehicles' control laws. Consequently, the PDE will depend on the speed average value of the set of vehicles generated by the ODEs. Such a mixed model could allow more accurate estimations of the system's global (macroscopic and microscopic) state. Such reliable estimations could be used to design more efficient control algorithms that eliminate the stop-and-go oscillations.

The *scientific objective* of the thesis is to improve the already existing traffic control methods that ensure string stability or maximum traffic throughput by removing the assumptions that the two-level visions are not connected. Then, the goal is to ensure string stability when considering each vehicle in a platoon as part of the whole traffic flow, and jointly select the best microscopic behavior with respect to the current traffic conditions. The principal steps of the proposed work are listed as follows

- numerically analyze the differences between the PDE and ODE models in a similar scenario, and compare the two models;

- define a suitable definition of stability for the resulting mesoscopic system (combining global stability and string stability);
- Explicit design of control laws and observers in the general case of a mesoscopic system. The robustness properties of these control laws will be considered. This part will be investigated in collaboration with Jean AURIOL, expert in the domain of control for PDE for traffic control systems.
- Implementation of the developed techniques in simulation and validation. An implementation on real systems could also be considered (robot Turtlebots).

Required skills:

This thesis topic mainly requires good skills in control theory and mathematics (Grandes Ecoles or Master in mathematics/control). Very good results in the engineering curriculum as well as expertise in the topics related to nonlinear control of ordinary or partial differential equations will constitute strengths to the proposed subject. The proposed subject should lead to the acquisition of strong theoretical skills in the field of control of traffic systems. In particular, the candidate will become familiar with the modeling of dynamical systems, with control design and with string stability. The candidate should also become familiar with Matlab (numerical methods, simulations) or Python.

Application: Send

- CV
- A letter of motivation
- Master's and/or engineering studies evaluations
- A letter of recommendation from the master manager
- The coordinates of two referees

Contact: Send your application by email to

- Alessio IOVINE (alessio.iovine@centralesupelec.fr)
- Silviu NICULESCU (silviu.niculescu@centralesupelec.fr)

References:

[Feng et al. (2019)] S. Feng, Y. Zhang, S. E. Li, Z. Cao, H. X. Liu, andL. Li, "String stability for vehicular platoon control: Definitions and analysis methods," Annual Reviews in Control, vol. 47, pp. 81–97, March 2019.

[Mirabilio et al. (2021)] M. Mirabilio, A. Iovine, E. De Santis, M. D. Di Benedetto and G. Pola, "String Stability of a Vehicular Platoon With the Use of Macroscopic Information," in IEEE Transactions on Intelligent Transportation Systems, vol. 22, no. 9, pp. 5861-5873, Sept. 2021.

[Chen et al. (2021)] Y. -J. Chen, X. -G. Li, Y. Zhang, S. -I. Niculescu and A. Çela, "Stability Analysis of Car-Following Systems With Uniformly Distributed Delays Using Frequency-Sweeping Approach," in *IEEE Access*, vol. 9, pp. 69747-69755, 2021, doi: 10.1109/ACCESS.2021.3077513.

[Siri et al. (2021)] S. Siri, C. Pasquale, S. Sacone, A. Ferrara, "Freeway traffic control: A survey", Automatica, Volume 130, 2021, 109655, ISSN 0005-1098.

[Hu et al. (2021)] H. Yu, J. Auriol, M. Krstic, "Simultaneous Downstream and Upstream Output-Feedback Stabilization of Cascaded Freeway Traffic", Automatica, 2021.