Master internship position
Machine learning and mixed ODE-PDE for a mesoscopic traffic control systems

Subject: Development and implementation of PDE-ODE traffic models for control purposes.
Student profile: master student (bac+5) in control systems or mathematics or statistics; experience in traffic control is appreciated but not mandatory.
Duration: internship of 5-6 months, possibly starting mid February-March 2027.
Salary: 600-700 €, according to the working days of the month.
Work place: L2S, CentraleSupélec, 3, rue Joliot Curie, 91190 Gif-sur-Yvette, France.
Keywords: nonlinear control, PDE models, machine learning, parameter estimation, coding.
Advisors: Jean Auriol, l2s.centralesupelec.fr/u/auriol-jean/
(email jean.auriol@centralesupelec.fr)
Alessio Iovine, l2s.centralesupelec.fr/u/iovine-alessio/
(email alessio.iovine@centralesupelec.fr)
Xujia Zhu, l2s.centralesupelec.fr/u/zhu-xujia/
(email xujia.zhu@centralesupelec.fr)

Internship description

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

- 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);
- 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).

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.

The goal is to consider 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 stage's first target is to numerically analyze the differences between the PDE and ODE models in a similar scenario. The hired person will study already existing macroscopic and microscopic traffic models and their implementation in Python with the mismatch quantification by machine learning approaches. In the next step, she/he is expected to compare the two models and to tune the different physical parameters

of the macroscopic model such that the two models present similar behaviors. Then, the resulting ODE-PDE model will be used to control prospects. The intern should first define a suitable definition of stability for the resulting mesoscopic system (combining global stability and string stability) before focusing on the design of a stabilizing control law. Thus this internship spans the full range from theoretical research to simulations and data analysis. The desired steps are described as follows:

1. Literature investigation;
2. Comparison of the PDE and ODE approach for traffic control purposes on existing Python software;
3. Mismatch quantification by machine learning;
4. Compatibility investigation of the ODE modeling with PDE characteristics;
5. Proposition of a stability concept for the PDE-ODE model.

Remark: an interested student could follow up the project with a PhD on the same subject.

Desired experience

(a) notions of dynamical systems (ODE and PDE);

(b) parameter identification by machine learning;

(c) notions of control theory, controller design, stability;

(d) interest in traffic control problem;

(e) MATLAB, python;

(f) LaTeX.

References

[1] L. Prade Njoua Dongmo, J. Auriol and A. Iovine, "Smart Traffic Manager for Speed Harmonization and Stop-and-Go Waves Mitigation Dedicated to Connected Autonomous Vehicles," in IEEE Transactions on Control Systems Technology, vol. 33, no. 4, pp. 1447-1462, July 2025.
[2] H. Yu, J. Auriol, M. Krstic, "Simultaneous Downstream and Upstream Output-Feedback Stabilization of Cascaded Freeway Traffic", Automatica, 2021.
[3] 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.
[4] 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.
[5] A. Spiliopoulou, I. Papamichail, M. Papageorgiou, Y. Tyrinopoulos, and J. Chrysoulakis, "Macroscopic traffic flow model calibration using different optimization algorithms". Operational Research, vol. 17, pp. 145–164, 2017.
[6] N. Polson and V. Sokolov. “Bayesian analysis of traffic flow on interstate I-55: the LWR model” The Annals of Applied Statistics, vol. 9, no. 4, pp. 1864–88, 2015.
[7] R. Tuo and C. F. Jeff Wu. "Efficient calibration for imperfect computer models." Annal of Statistics, vol. 43, no. 6, 2331–2352, 2015.

Contacts
Send a CV, a motivation letter, transcripts of academic records and names of possible references with object [stage Traffic].
The position is available immediately and applications will be accepted until this position is filled. A National Security clearance is needed, and it can require approximately 2 months.