NATIONAL PH.D. PROGRAM IN AUTONOMOUS SYSTEMS

Stability and security of interconnected platoons of vehicles

Ph.D. candidate

Pietro BONSANTO

Cycle

XXXIX

Tutors

Maria Domenica Di Benedetto

1. Description of the research program

In the face of global urbanization and the subsequent surge in vehicle ownership, a host of challenges have emerged, ranging from safety concerns to fuel inefficiency, traffic congestion, and environmental pollution. To address these multifaceted issues, researchers are delving into cutting-edge traffic management solutions enabled by breakthroughs in electronics, telecommunications, and computer technologies. Among these advancements, Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) technologies are emerging as central components of intelligent transportation systems. Scholars advocate strategies that combine intelligent infrastructure for traffic management with the integration of autonomous vehicles. These autonomous vehicles, whether operating in platoons or alongside traditional traffic, hold the promise of alleviating congestion, conserving fuel, and reducing accidents. Thus, the implementation of effective control policies becomes paramount, utilizing shared data to optimize traffic flow and mitigate disruptions such as traffic waves.

As traffic technology advances, interconnectivity and sophistication in devices have given rise to complex systems. These intricate systems require stability tools akin to those used for vehicular platoons. Ensuring stability becomes crucial for complex networks grappling with escalating intricacy. This study aims to tackle traffic challenges by exploring smart mobility and connecting intelligent agents. It delves into the benefits of sharing macroscopic information within autonomous vehicle platoons, with the goal of enhancing traffic control through discrete time and hybrid system design, ultimately promoting string stability. Recent efforts in the field have led to the development of both microscopic and macroscopic models. The former examines individual vehicle behavior, detailing local dynamics with variables like position, speed, and acceleration, while the latter describes traffic flow using aggregated variables such as traffic density and flow. Macroscopic models primarily address collective phenomena, like congestion evolution and traffic wave propagation, without delving into individual vehicle dynamics.

The concept of traffic as a fluid or gas flowing through a conduit with vehicles as moving particles has led to the application of similar mathematical models. In continuous-time design, where measurements are available at every instant, this approach is effective. However, in more realistic scenarios of asynchronous communication, a sampled-data framework proves invaluable. In an ideal scenario devoid of interruptions, this strategy minimizes communication and computational load. Macroscopic information influences only a few variables in local controllers, bridging the gap between macro and micro scales, giving rise to a mesoscopic structure. Building on this foundation, the study advances to establish conditions that dampen perturbations, such as shifts in reference speed, coursing through vehicle platoons, ensuring consistent vehicle spacing and promoting smooth traffic flow.

As the study transitions into the real world, it focuses on disturbances affecting individual vehicles within platoons, guiding micro-level control through macroscopic information. The framework introduces "Disturbance String Stability," a concept evolving from classical String Stability tailored to this context. It sets conditions to restrain perturbations and limit external disturbances' impact, fostering a harmonious relationship between vehicles and their environment. This research extends the concept of String Stability to Large-Scale Interconnected Systems (LSSs) characterized by diverse topologies and resilience to external disruptions, resulting in "Scalable Mesh Stability (sMS)." This framework establishes interaction conditions required for stability and perturbation control, with applications extending beyond vehicular contexts to systems like microgrid interconnections.

In the pursuit of enhancing passengers' experiences, the study may delve into the utilization of Model Predictive Control (MPC) with human-like adaptability, particularly in adaptive cruise control systems. This approach, which transcends linear models, takes into account a broader range of vehicle dynamics and predictive elements to optimize control actions over a finite prediction horizon. MPC integrates real-time data and predictions to facilitate adaptable control, addressing challenges like communication lag and variable measurements within platooning, thus refining traffic for safety and efficiency.The expected outcomes of this research include the potential to achieve string stability using mesoscopic information, reducing the need for complete vehicle information. Additionally, it promises a range of environmental benefits such as improved traffic flow, reduced pollution, and optimized fuel consumption.

Schedule of the research activities

Insert the research activities that you plan, or you have completed for the three years, including any period abroad.

First academic year (Planned)

	Description	Period	Activity abroad
Literature Review	Review of the existing literature regarding vehicular platoons and their stability and string stability, from both a macroscopic and microscopic perspective	November 2023-October 2024	University of Califronia Berkeley

Second academic year (Planned)

	Description	Period	Activity abroad
Sampled-data adaptation of vehicular platoons	String stability is the key starting point of the research, which aims at embedding the sampled-data framework into the one of vehicle platoons, in order to introduce advanced control techniques. In this phase how to embed and improve the vehicular platoons into the SD framework will be investigated.	November 2024-October 2025	Ecole Centrale Paris, Supélec
Scalable Mesh Stability	Once achieving a SD framework for vehicular platoons, this phase aims at enlarging the string stability concept to cope with possible disturbances introducing Scalable Mesh Stability	May- October 2025 (TBC)	NO (TBC)

Third academic year (Planned)

	Description	Period	Activity abroad
Adaptive Control for platoons	After studying under which conditions stability can be ensured under sampling, in this phase the focus shifts to achieving adaptive control techniques applied to cruise control, together with MPC foundations	November 2025-February 2026	NO (TBC)
Final testing of the Control System	This final phase will ensure the satisfaction of good performances for the overall control system that will be developed	November 2025-October 2026	NO (TBC)

2. Training and research activities plan

First academic year (Planned)

	Description	Period	Final Exam	ECTS
A. Ph.D. courses	Game Theory for Controlling Autonomous Systems	15/04/24-19/04 /24	Yes	3
	Theory and Applications of Contracting Dynamical Systems	11/06/2024-14/06/2024	Yes	3

	From Least Squares to Subspace Identification The Scenario Approach: data science for systems, control and machine learning	TBD 24/06/2024-28/06/2024	Yes	2 3
B. Master's degree courses	Hybrid systems Control and Simulation	2nd semester 2024	Yes	6
C. Soft skill courses				
D. Participation to seminars	Participation to DEWS seminars and workshops that will concern the research area of the first year			6
E. Participation to international congresses or workshops				
F. Presentation of research products at international congresses or workshops				
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			23
G. Individual research activity	Literature review			25
H. Supervision of students	Supervision of the students under the guidance of a tutor			6
I. Integrative teaching activities	Integrative didactic activities will be carried out under the guidance of the tutor			6
J. Preparation of manuscripts for conferences or journals				
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			37
	TOTAL OF ECTS			**60**

Second academic year (Planned)

	Description	**Period**	**Final Exam**	**ECTS**
A. Ph.D. courses	At least one SIDRA course in Bertinoro	Summer 2024 (TBC)	Yes	4
	High-Gain Observers in Nonlinear feedback control	TBC	Yes	3
	One or two relevant phd courses	TBC	Yes	3
B. Master's degree courses				
C. Soft skill courses				
D. Participation to seminars	Participation to at least two seminars/ workshops according to availability			4
E. Participation to international congresses or workshops	Participation to international conferences according to availability			4
F. Presentation of research products at international congresses or workshops	Presentation of the results obtained possibly to CDC			3

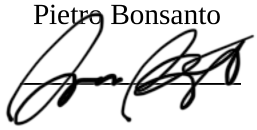
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			21
G. Individual research activity	Research work as mentioned in Second academic year including the training period abroad			20
H. Supervision of students	Supervision of students under the guidance of a tutor			6
I. Integrative teaching activities	Integrative didactic activities will be carried out under the guidance of the tutor			3
J. Preparation of manuscripts for conferences or journals	Manuscript preparation			10
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			39
	TOTAL OF ECTS			**60**

Third academic year (Planned)

	Description	Period	Final Exam	ECTS
A. Ph.D. courses				
B. Master's degree courses				
C. Soft skill courses				
D. Participation to seminars	Participation to at least one seminar/workshop according to availability			3
E. Participation to international congresses or workshops	Participation to international congresses or workshops according to availability			4
F. Presentation of research products at international congresses or workshops	Presentation of the results obtained to two international conferences or workshops associated to a high impact factor			4
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			11
G. Individual research activity	Research activities mentioned in the last academic year.			30
H. Supervision of students				
I. Integrative teaching activities	Relevant teaching activities under the supervision of tutor			9
J. Preparation of manuscripts for conferences or journals	Manuscript Preparation for One Journal Paper and Thesis			10
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			49
	TOTAL OF ECTS			**60**

3. List of the publications written by the candidate in the triennium

Pietro Bonsanto



Prof. Maria Domenica Di Benedetto