PhD in Information Technology and Electrical Engineering

Università degli Studi di Napoli Federico II

PhD Student: Alberto Petrillo

XXXI Cycle

Training and Research Activities Report – Third Year

Tutor: Stefania Santini

1. Information

    a. Alberto Petrillo, MS degree in Automation and control Engineering – Università degli studi di Napoli Federico II.
    b. XXXI Cycle- ITEE – Università degli studi di Napoli Federico II.
    c. Fellowship type: “Borsa di Ateneo”.
    d. Tutor: Stefania Santini.

2. Research activity

    a. Title: Cooperative control of autonomous connected vehicles from a Networked Control System perspective: Theory and experimental validation.

    b. Study: Networked control systems, Multi-agent systems, synchronization, time-delay systems, multiple communication time-varying delays, cyber security vulnerabilities, autonomous ground vehicles, smart and autonomous system.

    c. Research description

    Formation control of autonomous connected vehicles is one of the typical problems addressed in the general context of networked control systems. By leveraging this paradigm, a platoon composed by multiple connected and automated vehicles is represented as one-dimensional network of dynamical agents, in which each agent only uses its neighboring information to locally control its motion, while it aims to achieve certain global coordination with all other agents.

    Within this theoretical framework, control algorithms are traditionally designed based on an implicit assumption of unlimited bandwidth and perfect communication environments. However, in practice, wireless communication networks, enabling the cooperative driving applications, introduce unavoidable communication impairments such as transmission delay and packet losses that strongly affect the performances of cooperative driving. Communication time-delay and other networked-induced phenomena are hence crucial in cooperative driving application since they may lead the vehicular network to instability. Therefore, for the practical implementation of distributed strategies, they have to be taken into account from the beginning of the control design phase and the challenge in the control field is hence to design cooperative control algorithms that are resilient and robust to communication impairments. This problem has been tackled in the current literature under the restrictive assumption that the communication delay is unique (or homogeneous, uniform, identical as indifferently referred in the technical literature) and often constant. However, when treating with communication networks, each communication link, that connects a pair of vehicles, is affected by a different variable time-delay that depends from actual conditions, or possible impairments, of the communication channel. It follows that the hypothesis commonly made in the technical literature of a unique and constant network delay may result unrealistic and that delays, affecting the outdated information that are used to compute the control input, have to be considered as a multiple time-varying functions depending from the specific communication link under investigation. Indeed, time-delay itself might obey its own dynamics, which possibly depend on the communication distance, total computation load and computation capability.

    Moreover, in addition to this problem, wireless communication networks can suffer different security threats. In view of the fact that cyber attacks can lead to dangerous implications for the security of autonomous driving systems, it is fundamental to consider their effects on the behavior of the interconnected vehicles, and to try to limit them from the control design stage.

From control viewpoint, recent literature on the security of the networked cyber-physical systems is usually devoted to designing state estimators for the better understanding of system dynamical behaviors and the attack detection. The exploitation of the cooperation property of the networked control systems paradigm, or more precisely the exploitation of all information exchanged among the agents within the networked control system, could be also a promising solution so to counteract security vulnerabilities. However, many issues are still open, as for example the need of designing distributed control protocols able to cope simultaneously with network induced phenomena - such as the unavoidable delays that affect in practice the information shared via a wireless channel - and different kinds of possible cyberattacks.

Hence, from the literature overview on cooperative driving control strategies, and more in general on the networked control systems, the following main challenges arise:

1. Designing distributed cooperative control algorithms that are resilient and robust to multiple time-varying communication delays and packet losses.
2. Designing resilient secure distributed control algorithms able to counteract different security vulnerabilities when considering the wireless communication network non-ideal.

The aim of my research activity is to tackle and solve both the challenges by proposing different properly designed control strategies.
They are validated in analytical, numerical and experimental ways. Obtained results confirm the effectiveness of the strategies in coping with communication impairments and security vulnerabilities.

3. Products

a. Publications

i. Conference Paper

1. Giovanni Fiengo, Alberto Petrillo, Alessandro Salvi, Stefania Santini and Manuela Tufo, "A control strategy for reducing traffic waves in delayed vehicular networks." *55th IEEE Conference on Decision and Control (CDC), 2016*. IEEE, 2016.

2. Alberto Petrillo, Antonio Pescapé and Stefania Santini. "A collaborative control strategy for platoons of autonomous vehicles in the presence of message falsification attacks." *5th IEEE International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS)*.IEEE, 2017.

3. Marco Di Vaio, Guido Guizzi, Alberto Petrillo and Stefania Santini. “Fleets Management of Cooperative Connected Automated Vehicles in Manufacturing Processes.” CIISE 2017 -Conferenza INCOSE Italia su Systems Engineering 2017.

4. Giovanni Fiengo, Dario Giuseppe Lui, Alberto Petrillo, Stefania Santini and Manuela Tufo. “Distributed Leader-Tracking for Autonomous Connected Vehicles in Presence of Input Time-Varying Delay”. *26th Mediterranean Conference on Control and Automation (MED)*. IEEE,2018.

5. Marco Amodeo, Marco Di Vaio, Alberto Petrillo, Alessandro Salvi, Stefania Santini. “Optimization of fuel consumption and battery life cycle in a fleet of Connected Hybrid Electric Vehicles via Distributed Nonlinear Model Predictive Control”. *European Control Conference (ECC) 2018.* To appear.

6. Marco Di Vaio, Alberto Petrillo and Stefania Santini. "On the Robustness of a Distributed Adaptive Synchronization Protocol for Connected Autonomous Vehicles with Multiple Disturbances and Communication Delays". *57th IEEE Conference on Decision and Control (CDC)*. Accepted.

7. Diego Iannuzzi, Stefania Santini, Alberto Petrillo and Procolo Ivan Borrino. "Design Optimization of Electric Kart for Racing Sport Application". *5th edition of the International Conference on Electrical Systems for Aircraft, Railway, Ship Propulsion and Road Vehicles (ESARS) and International Transportation Electrification Conference (ITEC)*.IEEE 2018. Accepted.

8. Francesco Flammini, Stefano Marrone, Roberto Nardone, Valeria Vittorini, Stefania Santini and Alberto Petrillo. "Towards Railway Virtual Coupling". *5th edition of the International Conference on Electrical Systems for Aircraft, Railway, Ship Propulsion and Road Vehicles (ESARS) and International Transportation Electrification Conference (ITEC)*. IEEE 2018. Accepted.

ii. Journal Paper

1. Alberto Petrillo, Alessandro Salvi, Stefania Santini, Antonio Saverio Valente, Petrillo. Adaptive synchronization of linear multi-agent systems with time-varying multiple delays. *Journal of the Franklin Institute*, *354*(18), 8586-8605.

2. Alberto Petrillo, Alessandro Salvi, Stefania Santini, Antonio Saverio Valente. "Adaptive multi-agents synchronization for collaborative driving of autonomous vehicles with multiple communication delays". *Transportation research part C: emerging technologies*, *86*, 372-392.

3. Alberto Petrillo, Antonio Pescapé and Stefania Santini. "A collaborative approach for improving the security of vehicular scenarios: The case of platooning". *Computer Communications*, *122*, 59-75.

4. Conferences and Seminars

a. Details

i. "*55th IEEE conference on Decision and Control*", Las Vegas, 12-15 December 2016.

ii. "*5th IEEE International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS)*", Napoli,Italy, 26-28 June 2017.

iii. "CIISE 2017 - Conferenza INCOSE Italia su Systems Engineering", Napoli, Italy 22 24 November 2017.

iv. European Control Conference (ECC) 2018, Lymassol Cyprus, 12-15 June 2018.

v. 14th IFAC WORKSHOP ON TIME DELAY SYSTEMS. June 28-30, 2018 Budapest.

b. Presentations made

i. Presentation of the paper "*A control strategy for reducing traffic waves in delayed vehicular networks*" at *55th IEEE conference on Decision and Control*, Las Vegas, 12-15 December 2016.

ii. Presentation of the paper "*A collaborative control strategy for platoons of autonomous vehicles in the presence of message falsification attacks*" at 5th IEEE International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS), Napoli, Italy, 26-28 June 2017.

iii. Presentation of the paper "Fleets Management of Cooperative Connected Automated Vehicles in Manufacturing Processes" at CIISE 2017 - Conferenza INCOSE Italia su Systems Engineering", Napoli, Italy 22-24 November 2017.

iv. Presentation of the paper "Optimization of fuel consumption and battery life cycle in a fleet of Connected Hybrid Electric Vehicles via Distributed Nonlinear Model Predictive Control" at European Control Conference (ECC) 2018.

v. Presentation of the work "A Collaborative control strategy for connected autonomous vehicles in the presence of communication delays and cyber-attacks" at 14th IFAC WORKSHOP ON TIME DELAY SYSTEMS. June 28-30, 2018 Budapest.

5. Activity abroad

a. Place: Gothenburg, Sweden.

b. Dates: 10/03/2018-30/06/2018.

c. Contact person: Professor Paolo Falcone (paolo.falcone@chalmers.se) of Chalmers University of Technology.

d. Description of the activity

Experimental validation of cooperative driving control strategies at urban intersection. The experimental validation campaign was carried out in collaboration with Professor Paolo Falcone of Chalmers University of Technology (Gothenburg, Sweden) and the Research Department of Ericsson (Gothenburg, Sweden).
Experiments were performed at AstaZero test track (near Gothenburg, Sweden) by exploiting three heterogeneous vehicles, properly equipped with specific communication and control hardware: Volvo Car XC90; Volvo Car S90; Volvo Truck FH16. Experimental results confirmed the effectiveness of the proposed approach in guaranteeing, in real on-the-road scenarios, the safe crossing of autonomous connected vehicles at traffic junctions. See the full video of the experiments at https://www.youtube.com/watch?v=rmjJkIlFMJ4 .

6. Summary of the PhD activities

Student: Alberto Petrillo alberto.petrillo@unina.it **Tutor: Stefania Santini** stefania.santini@unina.it **Cycle XXXI**

	Credits year 1								Credits year 2								Credits year 3									
	Estimated	1 bimonth	2 bimonth	3 bimonth	4 bimonth	5 bimonth	6 bimonth	Summary	Estimated	1 bimonth	2 bimonth	3 bimonth	4 bimonth	5 bimonth	6 bimonth	Summary	Estimated	1 bimonth	2 bimonth	3 bimonth	4 bimonth	5 bimonth	6 bimonth	Summary	Total	Check
Modules	13		6		3	4	4	17	13				12	3		15	0							0	32	30-70
Seminars	5		1,7	1,3	2			5	5	3,7	2,9					6,6	0							0	12	10-30
Research	42	10	2,3	7,7	7	5	6	38	42	6,3	7,1	10	3	4	8	38	60	10	10	10	10	10	10	60	136	80-140
	60	10	10	9	12	9	10	60	60	10	10	10	15	7	8	60	60	10	10	10	10	10	10	60	180	180