Università degli Studi di Napoli Federico II
PhD program in
Information Technology and Electrical Engineering

PhD Student: Bianca Caiazzo

Cycle: XXXV

Training and Research Activities Report

Academic year: 2020-21 - PhD Year: Second

student signature :

Tutor: Prof. Stefania Santini *tutor signature :*

Co-Tutor: Prof. Amedeo Andreotti

Date: October 21, 2021

1. Information:

- **PhD student: Bianca Caiazzo** **PhD Cycle: XXXV**
- **DR number: DR993884**
- **Date of birth: 24/08/1994**
- **Master Science degree: Management Engineering**
- **University: University of Naples Federico II**
- **Scholarship type: UNINA**
- **Tutor: Prof. Stefania Santini**
- **Co-tutor: Prof. Amedeo Andreotti**

2. Study and training activities:

Activity	Type[1]	Hours	Credits	Dates	Organizer	Certificate[2]
Telemedicina in Italia: casi di successo	Seminar	1.5	0.3	17/11/2020	Prof. Giovanni d'Addio	Y
Robot Manipulation and control	Seminar	2.5	0.5	17/11/2020	Prof. Bruno Siciliano	Y
Digital Management: practices, techniques, tools, and scientific approach	Seminar	2	0.4	18/11/2020	Prof. Giuseppe Longo; Prof. Dario Carotenuto	Y
L'esperienza del progetto di teleriabilitazione NEUROLAB	Seminar	1.5	0.3	24/11/2020	Prof. Giovanni d'Addio	Y
Images, Texts, Emojis & Geodata in a Sentiment Analysis pipeline	Seminar	1.5	0.3	25/11/2020	Prof. Giuseppe Longo; Prof. Serena Pelosi	Y
Telemedicina, e-health e mobile-health: si può davvero usare il digitale nel percorso assistenziale?	Seminar	1.5	0.3	26/11/2020	Prof. Giovanni d'Addio	Y

Patent Searching Best Practices with IEEE Xplore	**Seminar**	**1**	**0.2**	**27/11/2020**	**Dott. Eszter Lukacs**	**Y**
At the Nexus of Big Data, Machine Intelligence and Human Cognition	**Seminar**	**1**	**0.2**	**02/12/2020**	**Prof. Giuseppe Longo**	**Y**
From observability to privacy and security in discrete event systems	**Course**	**20**	**5**	**14/12/2020 - 12/01/2021**	**Prof. Gianmaria De Tommasi**	**Y**
From Photometric redshifts to improved weather forecasts: an interdisciplinary view on machine learning	**Seminar**	**1**	**0.2**	**13/01/2021**	**Prof. Giuseppe Longo; Dr. Kai Polsterer**	**Y**
Cybercrime and e-evidence: the criminal justice response	**Seminar**	**2**	**0.4**	**20/01/2021**	**Prof. Giuseppe Longo; Dr. Matteo Lucchetti**	**Y**
AI legal: Artificial intelligence for notary's sector- a case study	**Seminar**	**1**	**0.2**	**27/01/2021**	**Prof. Giuseppe Longo; Dr. Salvatore Palance**	**Y**
Machine learning: causality lost in traslation	**Seminar**	**1.5**	**0.3**	**20/02/2021**	**Prof. Giuseppe Longo; Prof. Edwin A. Valentijn**	**Y**
Approaches to graph machine learning	**Seminar**	**1**	**0.2**	**17/02/2021**	**Prof. Giuseppe Longo; Dr. Miroslav Cepek**	**Y**
Control System for Autonomous Ground Vehicles	**Course**	**-**	**6**	**I semester- a.a. 2020-2021**	**Prof. Stefania Santini**	**Y**
Visual Interaction and Communication in Data Science	**Seminar**	**2**	**0.4**	**03/03/2021**	**Prof. Giuseppe Longo; Dr. Marco Quartulli**	**Y**

Robo Ludens: a game design taxonomy for human-robot interaction	**Seminar**	**1**	**0.2**	**05/03/2021**	**Prof. Silvia Rossi (DIETI-UNINA); dr. Jojm Edison Munoz Cardona**	**Y**
“Parameter Sensitivity in Time Delay System”, Part of IFAC working group on Time-Delay Sistem	**Seminar**	**1**	**0.2**	**26/03/2021**	**Prof. Gabor Orosz; Prof. Gabor Stèpan**	**N**
Artificial Intelligence and 5G combined with holographic technology: a new perspective for remote health monitoring	**Seminar**	**2**	**0.4**	**26/05/2021**	**Prof. Giuseppe Longo; Dr. Pietro Ferraro; Dr. Pasquale Memmolo**	**Y**
“Delay-Adaptive Linear Control”, Part of IFAC working group on Time-Delay Sistem	**Seminar**	**1**	**0.2**	**11/06/2021**	**Prof. Gabor Orosz; Prof. Miroslav Krstic**	**N**
End-to-end optimization of augmented experience services over cloud-integrated 5G networks	**Seminar**	**4**	**0.8**	**15/06/2021 - 16/06/2021**	**5G academy- Dr. Jaime Llorca**	**N**
L’esposizione ai campi elettromagnetici generate dal Sistema 5G	**Seminar**	**4**	**0.8**	**16/07/2021**	**Prof. Nicola Pasquino (DIETI)**	**Y**
“Delays, dynamics and singularity tracking. A guided tour”, Part of IFAC working group on Time-Delay Sistem	**Seminar**	**1**	**0.2**	**10/09/2021**	**Prof. Gabor Orosz; Prof. Silviu-Iulian Niculescu**	**N**
2021 29th Mediterranean Conference on Control	**Research**	**-**	**-**	**22/06/2021 - 25/06/2021**	**Mediterranean Control**	**Y**

and Automation (MED) – Presentazione del lavoro sottomesso					**Association**	
16th IFAC WORKSHOP ON TIME DELAY SYSTEMS (TDS 2021) – Presentazione dei lavori sottomessi ; -Co-chair at the invited session "Recent advance on distributed control for Multi-Agent Systems"	**Research**	**-**	**-**	**29/09/2021 - 01/10/2021**	**International Federation of Automatic Control (IFAC)**	**Y**

1) Courses, Seminar, Doctoral School, Research, Tutorship
2) Choose: Y or N

2.1. Study and training activities - credits earned

	Courses	Seminars	Research	Tutorship	Total
Bimonth 1	0	2.5	7.5	0	10
Bimonth 2	5	1.3	3.7	0	10
Bimonth 3	6	0.8	3.2	0	10
Bimonth 4	0	1.4	8.6	0	10
Bimonth 5	0	0.8	9.2	0	10
Bimonth 6	0	0.2	9.8	0	10
Total	11	7	42	0	60
Expected	30 - 70	10 - 30	80 - 140	0 – 4.8	

3. Research activity:

Nowadays, Microgrids (MGs) paradigm has received a considerable attention to facilitate the integration of renewable Distributed Generation units (DGs) and, hence, to exploit their environmental benefits, as well as their economical, resilient and reliable advantages.

A MG is a cluster of interconnected DGs, loads and energy storage units which are collectively managed in order to increase the hosting capacity of DGs [1].

MG can operate in two modes, i.e., grid connected and islanded/stand-alone [2]. To ensure MG control, a three-layer hierarchical control architecture including Primary Control (PC), Secondary Control (SC) and Tertiary Control (TC) is typically proposed, where the secondary one plays a crucial role in the management of the islanded MG since it compensates voltage and frequency deviations induced by PC, thus allowing restoration to their reference values.

In the technical literature, SC strategies are implemented according to a centralized control paradigm (with low reliability) or to a decentralized/distributed one (with high reliability and reasonable cost), where according to the Multi-Agent Systems (MAS) modelling approach, the information sharing among units allows achieving common coordinated behaviour [3].

Up to now, important results have been achieved in the technical literature on the designing of distributed control strategies in MASs framework to solve leader-tracking consensus problem. Among the various control approaches, Proportional-Integral (PI) and Proportional-Integral-Derivative (PID) control strategies have been widely used due to their closed-loop performances, robustness with respect to model mismatches and easy to implementation. However, despite these advantages, distributed PI or PID protocols are still slightly covered in the current literature and, generally, they are implemented under some simple assumptions for communication constraints, which make the scenario under investigation less realistic [4]. Indeed, the presence of unavoidable technological constraints during information exchange among agents through wireless/wired network cannot be neglected, thus implying the need to consider communication time delays in information sharing. Moreover, since the communication time-delay can compromise the closed-loop performances of the entire MAS, even bringing to instability phenomena [5], it is important to consider them from the beginning of the control design phase, thus obtaining a controller running via outdated information. Furthermore, in real communication networks, e.g., based on IEEE 802.11 protocol, for each communication channel connecting a pair of agents, different communication impairments and packet losses may occur, thus introducing heterogeneous time-varying delays. Then, delays have to be considered as time-varying functions depending on the specific communication link under investigation.

In this context, my study during this second year firstly focuses on the designing of a distributed PI control protocol that allows to guarantee exponential leader-tracking for high-order MASs in the presence of both heterogeneous time-varying delays and model uncertainties. Specifically, by exploiting the Lyapunov-Krasovskii theory combined with Halanay's inequality [5], I proved that a distributed PI control strategy can guarantee that each agent within the network tracks the desired reference behaviour as imposed by a virtual leader interacting with its neighbours and assumed to be globally reachable (i.e., there is a path, that can be directed or not, that links the leading agent with the others) [R6]. The derived exponential stability conditions are expressed as a set of Linear Matrix Inequalities (LMIs), whose feasibility proved the exponential convergence of the MAS closed-loop error dynamics and also allowed finding an estimation of the decay rate, which plays an important role to evaluate control performances [6]. Some numerical examples involving a network of linear oscillators are carried out by exploiting Matlab/Simulink simulation platform, while Yalmip Toolbox with SeDuMi solver is used to prove the feasibility of the LMIs.

In a MG control perspective, the use of distributed PI or PID control strategies for SC purposes, and in particular for voltage/frequency restoration problem, has been deeply investigated in the technical literature [7]. Indeed, in this application field, PID control strategy allows guaranteeing not only the removing of voltage/frequency deviations induced by the PC, but also the achievement of fast response to transient change (e.g., when load changing or plug-and-play situations of DGs occur).

However, in this case the problems of gains tuning as well as the low bandwidth may arise.

Therefore, the second crucial aspect investigated during this second year is related to the possibility of designing Sampled-Data Control (SDC) approaches able to overcome the very restrictive assumption of continuous communication among DGs, thus solving the heavy burden on the communication network issues, that commonly arising when deploying MG controllers in practice, and, hence, improving the computational control costs.

Along this line, I designed a distributed H_∞ sampled-data PID control strategy to solve the voltage restoration problem in inverter-based islanded MGs, while counteracting both unavoidable deviations due to PC as well as loads fluctuations [R7]. Specifically, according to [8], the controller exploits the concept of *artificial delays* by using the finite-difference approximation for derivative actions, thus leading to a time-delayed controller whose delayed term is tackled with its Taylor’s expansion, with the remainder in the integral form. It has been proved that this approximation preserves the stability if the delay is small enough [9]. The resulting delayed controller is implemented in sampled-data fashion by using time-delay approach [5], thus reducing the total amount of control signals used for stabilization and, hence, saving limited network communication resources. To analytically prove the exponential stability of the closed-loop MG network under the action of the resulting sampled-data PID controller, it is exploited Lyapunov-Krasovskii theory, that allows obtaining robust sampling-dependent stability conditions expressed as a set of LMIs. Some numerical examples are carried out on a simple MGs network, where a troublesome scenario is emulated (i.e., both load/references variations and plug-and-play situation occur), thus showing the effectiveness of the approach [R7].

References:

1. Schiffer, J., Zonetti, D., Ortega, R., Stanković, A. M., Sezi, T., & Raisch, J. (2016). A survey on modeling of microgrids—From fundamental physics to phasors and voltage sources. Automatica, 74, 135-150.
2. Andreotti, A., Caiazzo, B., Petrillo, A., & Santini, S. (2021). Distributed Robust Finite-Time Secondary Control for Stand-Alone Microgrids With Time-Varying Communication Delays. IEEE Access, 9, 59548-59563.
3. Dehkordi, N. M., Baghaee, H. R., Sadati, N., & Guerrero, J. M. (2018). Distributed noise-resilient secondary voltage and frequency control for islanded microgrids. IEEE Transactions on Smart Grid, 10(4), 3780-3790.
4. Shi, C. X., & Yang, G. H. (2018). Robust consensus control for a class of multi-agent systems via distributed PID algorithm and weighted edge dynamics. Applied Mathematics and Computation, 316, 73-88.
5. Fridman, E. (2014). Introduction to time-delay systems: Analysis and control. Springer.
6. Liu, X., & Lam, J. (2013). Relationships between asymptotic stability and exponential stability of positive delay systems. International Journal of General Systems, 42(2), 224-238.
7. Yang, B., Wang, J., Sang, Y., Yu, L., Shu, H., Li, S., ... & Yu, T. (2019). Applications of supercapacitor energy storage systems in microgrid with distributed generators via passive fractional-order sliding-mode control. Energy, 187, 115905.
8. Selivanov, A., & Fridman, E. (2018, December). Robust sampled-data implementation of PID controller. In 2018 IEEE Conference on Decision and Control (CDC) (pp. 932-936). IEEE.
9. Karafyllis, I. (2008). Robust global stabilization by means of discrete-delay output feedback. Systems & Control Letters, 57(12), 987-995.

4. Research products

[R1]. Andreotti, A., Caiazzo, B., Petrillo, A., Santini, S., & Vaccaro, A. (2020). Hierarchical Two-Layer Distributed Control Architecture for Voltage Regulation in Multiple Microgrids in the Presence of Time-Varying Delays. Energies, 13(24), 6507. (**Published**: 9 December 2020);

[R2]. Andreotti, A., Caiazzo, B., Petrillo, A., & Santini, S. (2021). Distributed Robust Finite-Time Secondary Control for Stand-Alone Microgrids With Time-Varying Communication Delays. IEEE Access, 9, 59548-59563. (**Published:** April 16, 2021);

[R3]. Caiazzo, B., Lui, D. G., Petrillo, A., & Santini, S. (2021, June). Distributed Robust Finite-Time PID control for the leader-following consensus of uncertain Multi-Agent Systems with communication delay. In 2021 29th Mediterranean Conference on Control and Automation (MED) (pp. 759-764). IEEE. (**Published:** June 22, 2021);

[R4]. Caiazzo, B., Lui, D. G., Petrillo, A., & Santini, S. (2021). Distributed Double-Layer Control for Coordination of Multi-Platoons approaching road restriction in the presence of IoV communication delays. IEEE Internet of Things Journal. (**Published**: August 05, 2021);

[R5]. 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. (**Published**: August 19, 2021);

[R6]. Caiazzo, B., Lui, D. G., Petrillo, A., Santini, S.. On the exponential leader-tracking control for high-order multi-agent systems via distributed PI strategy in the presence of heterogeneous time-varying delays. 16th IFAC Workshop on Time Delay Systems 2021. (**Accepted**);

[R7]. Caiazzo, B., Fridman, E., Petrillo, A., Santini, S.. Distributed Sampled-data PID Control for Voltage regulation in inverter-based islanded Microgrids using Artificial Delays. 16th IFAC Workshop on Time Delay Systems 2021. (**Accepted**)

[R8]. Andreotti, A., Caiazzo, B., Di Pasquale, A., Pagano, M. On Comparing Regressive and Artificial Neural Network Methods for Power System Forecast. AEIT 2021 International Annual Conference, 2th Virtual Edition. (**Accepted**)

5. Conferences and seminars attended

1. 2021 29th Mediterranean Conference on Control and Automation (MED):
   a. Date: June 22-25, 2021. Bari, Puglia, Italy. (Going to virtual conference)

   b. Presentation made: Presentation of the paper “Distributed Robust Finite-Time PID control for the leader-following consensus of uncertain Multi-Agent Systems with communication delay” at 2021 29th Mediterranean Conference on Control and Automation (MED), June 22-25, 2021.

2. 16th IFAC Workshop on Time Delay Systems 2021:
   a. Date: September 29-October 1, 2021. Guangzhou, China. (Going to virtual conference)

   b. Presentation made: Presentation of the paper "On the exponential leader-tracking control for high-order multi-agent systems via distributed PI strategy in the presence of heterogeneous time-varying delays" at 16th IFAC Workshop on Time Delay Systems 2021;

   c. Presentation made: Presentation of the paper "Distributed Sampled-data PID Control for Voltage regulation in inverter-based islanded Microgrids using Artificial Delays" at 16th IFAC Workshop on Time Delay Systems 2021;

   d. Co-chair at the invited session "Recent advance on distributed control of Multi-Agent Systems".

6. Periods abroad and/or in international research institutions

The period abroad has started on October 13, 2021, while a remote collaboration with the hosting institution abroad goes back to the beginning of this second year after attending "Time-Delay and Sampled-Data Systems" doctoral school at European Embedded Control Institute (EECI) 2020 (see the Training and Research Activities Report of the first year), where Prof. Emilia Fridman was lecturer.

The hosting institution is the Department of Electrical Engineering-Systems at Tel Aviv University (TAU), Israel, while the supervisor is Prof. Emilia Fridman, IEEE Fellow.

As an expert in networked control systems and time-delay systems, Prof. Emilia Fridman led me into the study of distributed and decentralized sampled-data control strategies for high-order systems by using useful tools of time-delay theory. Then, the investigated approach has been extended in the framework of Multi-Agent Systems (MASs) and, in particular, to solve the voltage leader-tracking problem in modern power network as Microgrids (MGs) applications.

The first result of the collaboration is the paper "Distributed Sampled-data PID Control for Voltage regulation in inverter-based islanded Microgrids using Artificial Delays" presented at 16th IFAC Workshop on Time Delay Systems 2021.

The effective period spent at TAU for this second year is 18 days (from October 13, 2021 to now).

7. Tutorship

8. Plan for year three

For the next third year, it is planned to stay at Tel Aviv University (TAU) (Department of Electrical Engineering-Systems) until the end of April 2022 under the supervision of Prof. Emilia Fridman in order to continue the exploration of sampled data control approaches by using time-delays systems theory, both for a single dynamical system and Multi-Agent Systems. The objective is to design novel fully-distributed sampled-data control strategies to solve the leader-tracking problem in Multi-Agent Systems, where the data sampling can be studied via time-delays systems theory, thus overcoming the communication network bandwidth and energy constraints issues, as well as reducing the amount of control signals used for stabilization. Moreover, since in Networked Control Systems (NCSs) the transmitted signals are sampled in time and are subject to time delays, it will be desirable to study robust stability also with respect to *transport* delays. These latter can be not only small and constant, but also large and unknown. Therefore, in order to compensate large transport delays, a predictor-based approach could be a suitable solution.

The theoretical results will be applied in the context of distributed cyber-physical energy systems, e.g., Smart Grids and Microgrids, that can be modelled according to Multi-Agent Systems mathematical framework, where several challenges arise related to voltage/frequency and power regulation problems. The validation of theoretical results will be carried out in a two-fold way: *i*) firstly, we consider a simplified MGs consisting of few Distributed Generation units, each of them represented as a simple double-integrator system; *ii*) a more realistic simulation platform will be developed by using Simscape tool within Matlab/Simulink environment in order to obtain a more precise representation of each component within the physical power network. In so doing, it will be possible to prove the robustness of the theoretical results.