Giacomo Basile

Advanced Telescope Control

Tutor: Prof. Stefania Santini

co-Tutor: Ing. Pietro Schipani

Cycle: XXXVII

Year: Second

My Background

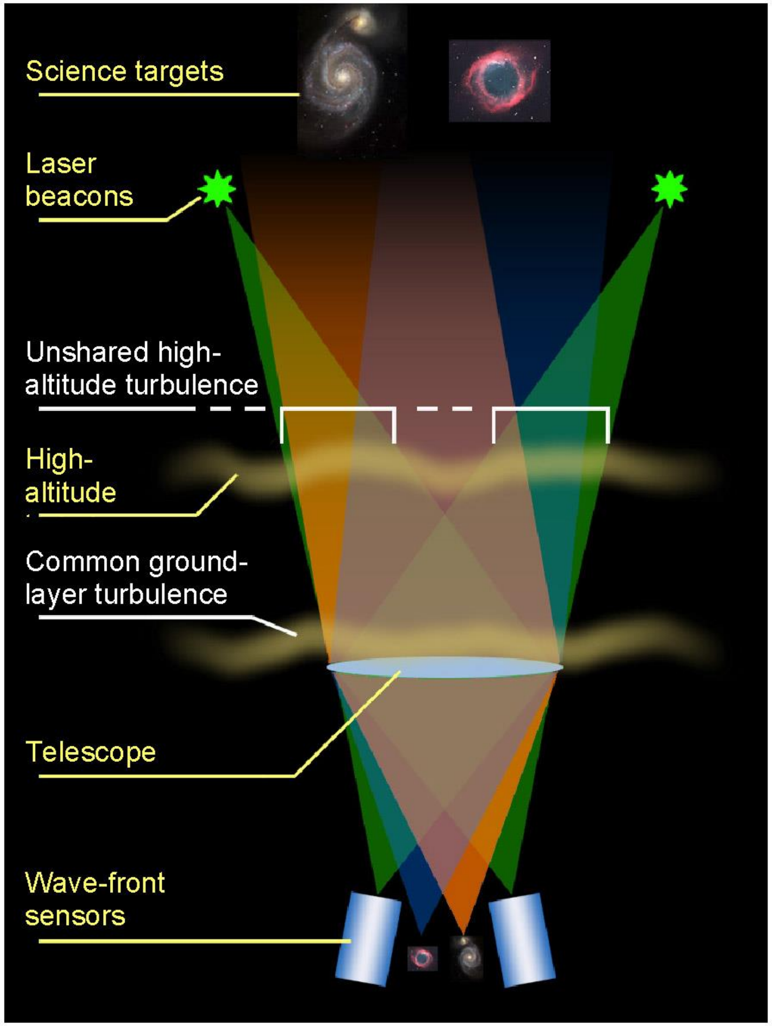
- MSc degree in Automation Engineering, University of Naples Federico II
- Research group: INAF and DAiSY Lab
- Tutor: Prof. Stefania Santini
- Co-Tutor: Ing. Pietro Schipani
- PhD start date: 01/11/2021
- Scholarship type: INAF
- Partner company Osservatorio Astronomico di Capodimonte

Research Field of Interest

Considering a novel astronomic telescope, e.g., Very or Extremely Large Telescope (VLT, ELT), my research topics are:

I. **The design and development of the adaptive optics (AO) Control Systems for ground-based telescopes, they aim to mitigate the atmospheric turbulence disturbance. Moreover, it is worthily noting that the AO control problem is intrinsically limited by:**

- **Spatial and fitting error.**
- **Temporal servo lag error.**
- **Angular or Anisoplanatic error.**



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   - **Spatial and fitting error.**
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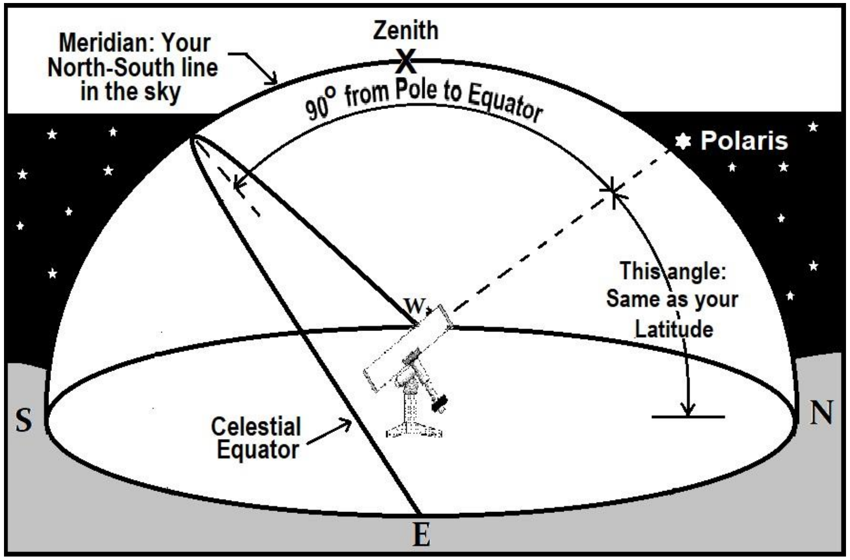
II. **The design and development of the axes Control System for ground-based telescope. Especially, the axes control system aims to pursuit the celestial body and it requires a very high tracking performance despite the presence of external disturbance such the wind force.**



Study & Training Activities (1/2)

The second-year activity is to deepen theoretical knowledge related to the state-of-the-art about architectures and strategies exploited to solve the AO control problem [1], mostly focused on the first numerical results obtained by applying the RL framework.

[1] Nousiainen, J., Rajani, C., Kasper, M., & Helin, T. (2021). Adaptive optics control using model-based reinforcement learning. *Optics Express*, *29*(10), 15327-15344.

Moreover, some effort has been also dedicated to the studying of the state-of-art for the axes control for ground-based telescope [2].

[2] Gawronski, W. K. (2008). *Modeling and control of antennas and telescopes* (p. 43). Berlin, Germany: Springer.

Finally, some first application of the of Deep Reinforcement Learning (DRL) techniques, as well as hybrid strategies for solution of optimal control problems have been investigated based on the following studies [3], [4].

[3] Berberich, J., Köhler, J., Müller, M. A., & Allgöwer, F. (2022, December). Stability in data-driven MPC: an inherent robustness perspective. In *2022 IEEE 61st Conference on Decision and Control (CDC)* (pp. 1105-1110). IEEE.

[4] Hewing, L., Wabersich, K. P., Menner, M., & Zeilinger, M. N. (2020). Learning-based model predictive control: Toward safe learning in control. *Annual Review of Control, Robotics, and Autonomous Systems*, *3*, 269-296.

Study & Training Activities (2/2)

-- Attended course are listed as follows --

- **EECI phd School: *"Nonlinear and data-driven model predictive control"*,** Prof. Frank Allgower and Prof. Matthias A. Muller.

- ***"Academic Entrepreneurship"*,** Prof. Pierluigi Rippa, Silvia Cosimato, Nadia Di Paola.

- ***"Information systems and business intelligence"*,** Prof. Flora Amato.

- Some of the attended seminars are listed as follows:

- ***"Back and forth between the infinite and the finite: a numerical view of time delay systems"*,** Prof. Dimitri Breda – ITEE-TDS.

- ***"From Cyber Situational Awareness to adaptive cyber defense: levelling the cyber playing filed"*,** Prof. M. Albanese – SSM.

Research Activity (1/2): Adaptive Optics control

Problem Statement:

- **Let's considering a novel astronomic telescope, e.g., Very or Extremely Large Telescope (VLT, ELT), the designing of a namely Adaptive Optic (AO) system is required to improve acquisition of the celestial body understudy. In detail, the AO system control aims to mitigate the atmospheric turbulence disturbance**

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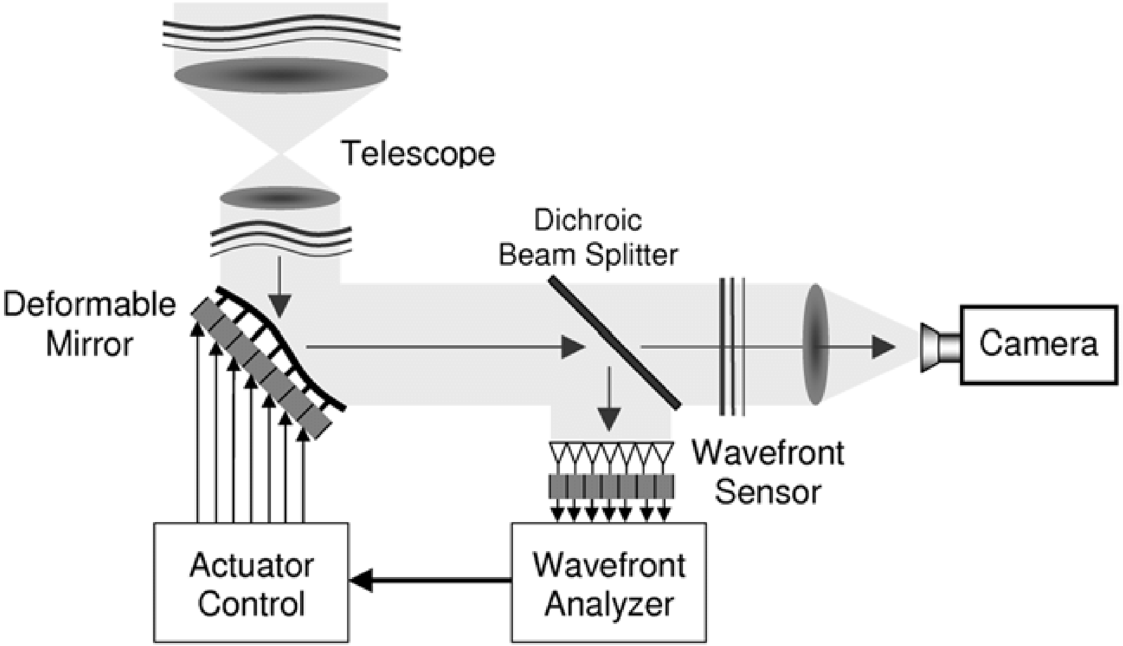
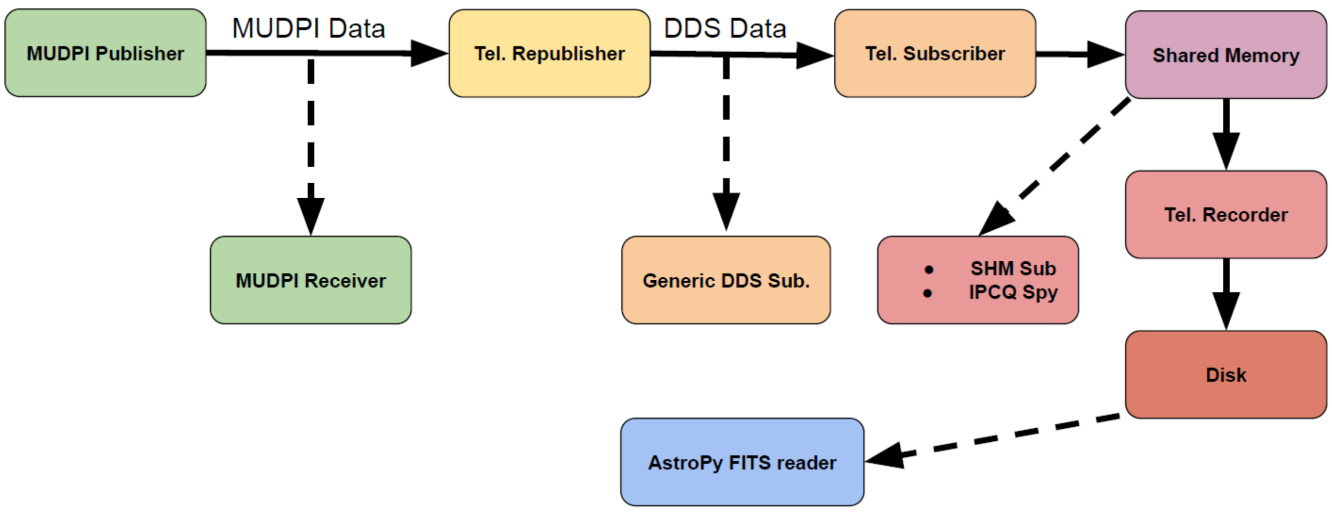
- **Ingredients:**
  - Distorted Wavefront
  - Deformable Mirror
  - Wavefront sensor
  - Actuator
  - Camera



Research Activity (1/2): Adaptive Optics control

- **During this second year, the focus was directed towards the development of a telemetry module (see exemplary figure) based on the control architecture of the ELT telescope project in which I have started attending the passed year. Specifically, the implementation of the module aims to test, in real-time scenario, the adaptive optics control algorithms that will be designed for the ELT project, and, also to numerical validate AO control system for future project.**



Research Activity (2/2): Axes telescope control

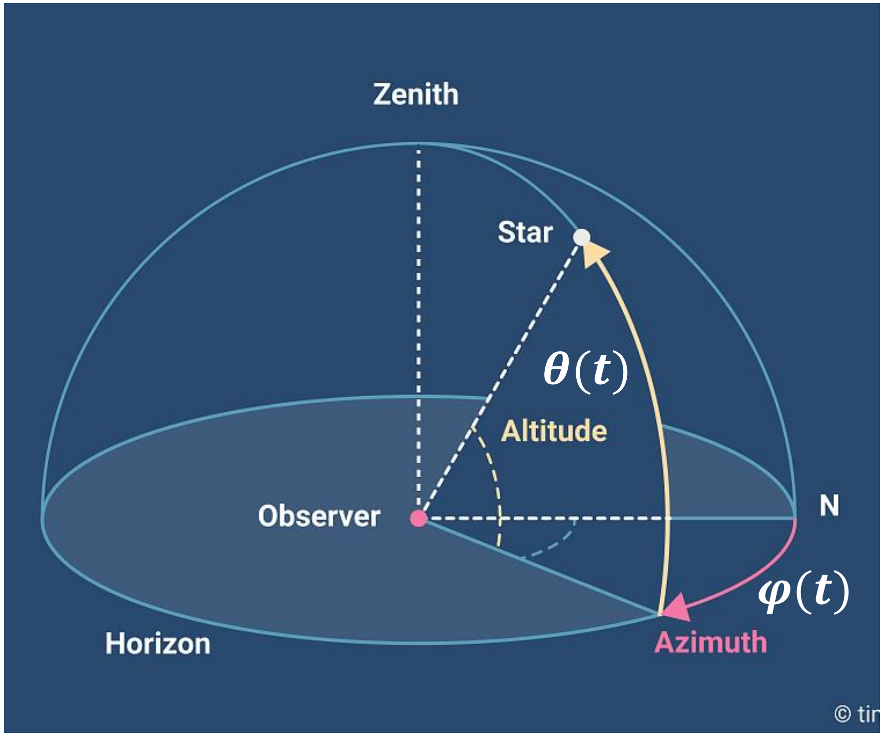
Problem Statement:

- **Let's considering a novel astronomic telescope, e.g., Very or Extremely Large Telescope (VLT, ELT), regarding axes control problem is decoupled by considering the azimuth coordination system, i.e.:**

  $i)$ the elevation axes $\theta(t)$.

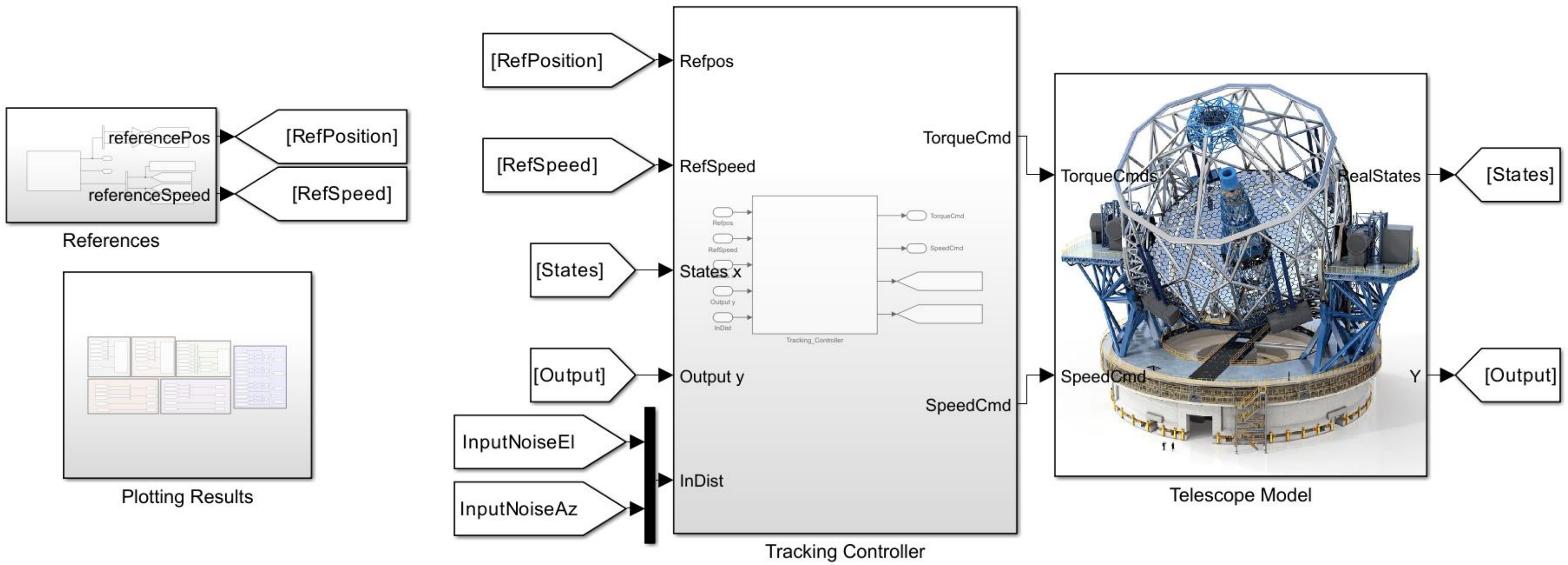
  $ii)$ the azimuth axes $\varphi(t)$.

- **Moreover, the axes controller have to cope with:**
  - Unmodelled dynamics
  - External disturbance such as the wind force
  - Mitigate the measurement noise



Research Activity (2/2): Axes telescope control

- **Within this framework, considering as case study the *"Telescopio Nazionale Galielo"* (TNG), I, firstly, provided the identification of the axes dynamical behavior of the TNG by the exploitation of real-data. Then an advanced Matlab&Simulink simulation platform has been implemented in order to validate the axes control loop.**



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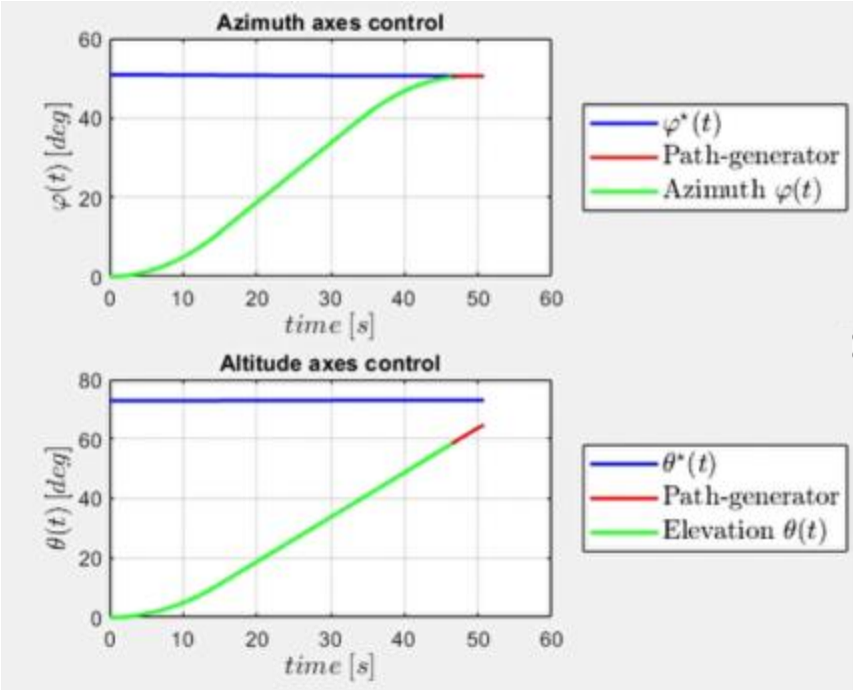
- **Specifically, the platform allow to validate, several control components:**
  - **Path-generator**
  - **Axes Controllers:**
    - PI + feedback gain controller
    - LQGPI + feedback gain Controller
    - MPC controller



Year Three: Open Challenges

- **With respect to the AO control instrument, the main objective is to design hybrid control architectures, e.g., MPC + DRL, and/or data-driven control strategies in order to deal with delays, uncertain parameters and external disturbance, such as: *i*) External disturbances, heat disturbance, and wind; *ii*) Servo lag and wave propagation delay.**

  Then, those strategies will be test on the real-time platform.

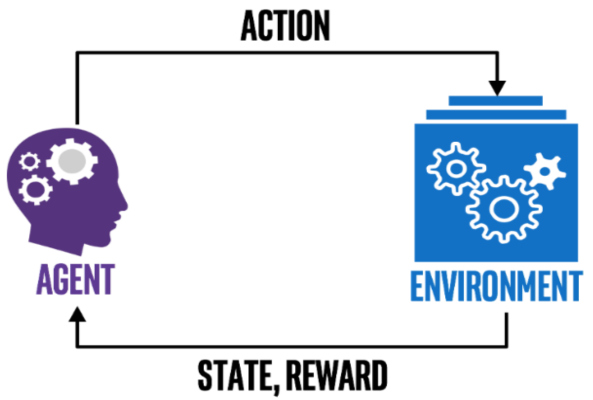
- **While, with respect to the axes control problem, the aims of the next years is to design and test a DRL-based controller in the real application such as the TNG ground-based telescope. In detail, the objective is to development and test, in real-time simulation, the designed controller algorithms, plus the DRL one, and compere the tracking performances.**

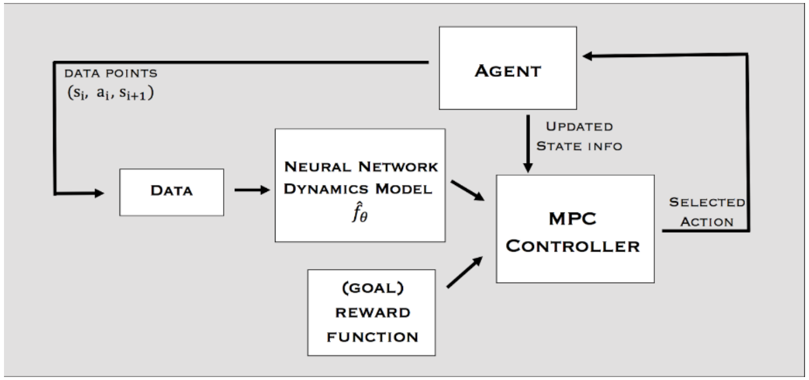
- **Regarding the theoretical results on the DRL approaches, the objective of the next year is to move toward the stability analysis for DRL-based control strategy.**

- **Testing and validation on realistic benchmark configurations are the final goals. The ESO standard test systems will be examined for the applicability of the proposed model.**

Further Topics: DRL & Hybrid controller

- **Besides, during the second year, the research activity regarding the Reinforcement Learning and Hybrid control strategies are investigated:**
  - With application on Single and Multi-Agent systems, I have provided a Deep Reinforcement learning (DRL) based controller. Specifically, the DRL controller, by interacting with the environment (i.e., a VCTS virtual platform) learned the correct behavior to impose to the agent in order to achieve the control goals.
  - With application only on Multi-Agent systems. I have designed a hybrid control strategy that combine the Model Predictive Control (MPC) and the Machine Learning inference model, such as the Long Short-Term Memory (LSTM) Neural Network, in order to achieve the cooperative control goals.





2^{nd} Year Products

[C1] Savarese, S., Schipani, P., Fiorentino, G., Schreiber, L., **Basile, G.,** Capasso, G., ... & Perrotta, F. (2022, August). Modeling wide-field telescopes in presence of misalignments: an application to the Vera C. Rubin Observatory. In *Modeling, Systems Engineering, and Project Management for Astronomy X* (Vol. 12187, pp. 557-565). SPIE.

[C2] **Basile, G.**, Lui, D. G., Petrillo, A., & Santini, S. (2022, December). *Deep deterministic policy gradient-based virtual coupling control for high-speed train convoys*. In 2022 IEEE International Conference on Networking, Sensing and Control (ICNSC) (pp. 1-6). IEEE.

[C3] **Basile, G.**, Leccese, S., Petrillo, A., Rizzo, R., & Santini, S. (2023, March). *Sustainable DDPG-based Path Tracking For Connected Autonomous Electric Vehicles in extra-urban scenarios*. In 2023 IEEE IAS Global Conference on Renewable Energy and Hydrogen Technologies (GlobConHT) (pp. 1-7). IEEE.

[C4] **Basile, G.**, Lui, D. G., Petrillo, A., & Santini, S. (2023, June). *Adaptive Distributed PI-like Control Protocol for the Virtual Coupling of Connected Heterogeneous Uncertain Nonlinear High-Speed Trains*. In 2023 31st Mediterranean Conference on Control and Automation (MED) (pp. 674-679). IEEE.

[C5] **Basile, G.**, Petrillo, A., & Santini, S. *LSTM-based Predictive Control for the TNG Axes Control*. In 2024 American Control Conference (ACC). IEEE. **(submitted)**.

[J1] **Basile, G.**, Napoletano, E., Petrillo, A., & Santini, S. (2022). Roadmap and challenges for reinforcement learning control in railway virtual coupling. Discover Artificial Intelligence, 2(1), 27.

Thank for your time!

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