PhD Program in Bioengineering and Robotics

Curriculum: Robotics and Autonomous Systems

Research themes

The main goal of the PhD curriculum in *Robotics and Autonomous Systems* is to study, design and build novel solutions and behaviors for robots, teams of robots and, in general, autonomous systems capable of exhibiting a high degree of autonomy and intelligence when performing highly complex tasks in challenging real-world environments.

The focus of the curriculum is two-fold: on the one hand, on key, innovative and disruptive methodologies and technologies, including such topics as sensing, state estimation, knowledge representation, software architectures for robots, real-time scheduling, motion planning, advanced robot control, robot coordination and cooperation, human-robot interaction and collaboration, design of macro/micro robot systems, design of sensors and actuators; on the other hand, on specific areas, e.g., underwater operations, aerial and space, or Industry 4.0, as well as on such diverse application scenarios as manufacturing, material handling and transportation, search & rescue, surveillance and monitoring, ambient assistive living).

The curriculum enforces research practices and education methodologies based on cutting-edge best practices at the international levels, and all the aspects outlined above are dealt with by focusing on the study and the adoption of theoretically sound methodologies and the design of experimentally verifiable solutions, with the goal of meeting robustness and predictability requirements even in unknown, dynamically changing, or even hazardous environments.

The ideal candidates are students with a higher-level University degree, with a strong desire for investigating, designing and developing robot-based systems which can have a huge, disruptive, impact on the society in the upcoming future.

International applications are strongly encouraged and will receive logistic support with visa issues and relocation.

Coordination and control of autonomous robots

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Project Description

Each applicant must submit a research proposal addressing (only) one of the following 2 topics

Research theme 1 (Coordinated payload transportation by a team of UAVs)

The use of multiple Unmanned Aerial Vehicles (UAVs) offers the possibility to study different applications in complex environments, from cooperative task assignments such as monitoring wide areas to formation control and cooperation for a mutual goal, including autonomously transporting a payload [1].

New controlling techniques should be developed for a system composed of multiple UAVs (quadrotors) transporting a payload by flexible rods [2][3].

Utilizing more agents enables carrying heavier payloads during mid to-long-term missions, reducing battery energy consumption per robot in the team. Despite these advantages, cooperative transportation poses several challenging situations, which can be explored related to (among others): coordinated takeoff and landing, recovery strategies in case of a UAV failure, cooperative formation control and reconfiguration basing on onboard sensors.

Requirements:

- Classical Control/Optimal Control
- State estimation and Filtering
- familiarity with ROS/ROS2 environment
- C++/Python
- Matlab/Simulink
- PX4 (optional)

References:

[1] D. K. D. Villa, A. S. Brandão, R. Carelli and M. Sarcinelli-Filho, "Cooperative Load Transportation With Two Quadrotors Using Adaptive Control", in IEEE Access, vol. 9, pp. 129148-129160, 2021.

[2] K. Sreenath, V. Kumar, "Dynamics, Control and Planning for Cooperative Manipulation of Payloads Suspended by Cables from Multiple Quadrotor Robots", Robotics: Science and Systems, 2013.

[3] M. Tognon, C. Gabelleri, L. Pallottino, A. Franchi, "Aerial Co-Manipulation with Cables: The Role of Internal Force for Equilibria, Stability, and Passivity", IEEE Robotics and Automation Letters, vol. 3 no. 3, pp. 2577-2583, 2018.

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Research theme 2 (Machine learning methods for active identification)

The research will focus on system identification methods with particular attention to the role of the control action to improve (online) the performance in terms of identification accuracy over a finite time.

As for the system model, the so-called “black box” paradigm will be addressed. No specific structure for the system to be identified will be assumed.
Machine learning methods will be addressed. Use of parametrized approximation structures will be considered whose complexity could be tuned a priori or (possibly) modified online, to reach a suitable trade-off between model accuracy and online computational requirement.
The research will address methods for on-line tuning the parameters of the approximating structure and for optimizing the control actions to be used to improve the model accuracy.
Applications could include exploration of unknown environments performed by autonomous robots and human-robot interactions, where mathematical models for the involved dynamics are not a-priori available.

Requirements:

- Skills in system Identification, machine learning, optimal control.

References:

[4] L. Scardovi, M. Baglietto, T. Parisini, “Active State Estimation for Nonlinear Systems: a Neural Approximation Approach”, IEEE Trans. on Neural Networks, vol. 18, no. 4, pp. 1172-1184, 2007.

[5] A. Alessandri, M. Baglietto, G. Battistelli, M. Gaggero “Moving-horizon State Estimation for Nonlinear Systems Using Neural Networks”, IEEE Trans. on Neural Networks, vol. 22, no. 5, pp. 768-780, 2011.

[6] M. Z. Babar, M. Baglietto, “Optimal feedback input design for dynamic nonlinear systems”,International Journal of Control, vol. 94, no. 8, pp. 2264-2281, 2021.

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