NATIONAL PH.D. PROGRAM IN AUTONOMOUS SYSTEMS

Control Strategies for Energy Harvesting Systems

Ph.D. candidate

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Cycle

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Tutors

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1. Description of the research program

Energy harvesting systems and the related control problems have attracted the attention of many researchers in recent years. Depending on the applicative contexts the energy sources can be different, but the purpose is always that of recovering the energy that would otherwise be lost. In automotive engineering, examples include energy recovering and conversion from exhaust emission in turbocharged car engines, the absorption of the kinetic energy in the brakes, the vibrations of the engines and the suspension systems. If such systems did equip a hybrid or electrical vehicle, the harvested energy could be used to recharge the vehicle's battery and hence extend its mileage. In the context of sensor networks, it provides a means of powering electronics where there are no conventional power sources, eliminating the need for frequent battery replacements. This is especially true in underwater or marine applications.

The focus of the research will be on the study and development of control strategies suitable for the maximization of the harvested energy while satisfying, at the same time, other control specifications. This is the case, for example, in regenerative suspension systems where the maximization of the energy harvested by road unevenness has to be traded off with other requirements, such as the desired drive comfort and road handling. In other cases, as in wind-turbine or wave energy conversion, the maximization of the recovered energy is a major concern and the challenges are more related to maintaining the operation within safe operative constraints. It is well known that the optimal solution in most cases is anti-causal (it depends on the future of some exogenous signals) and one of the challenges will be to find suitable causal approximations. Model Predictive Control (or Economic MPC) strategies seem to offer a good starting point for their capability to deal with future predictions of system variables, optimizing the control actions with respect to meaningful cost indices and inherently handling constraints. The research will be assessed by cases study on regenerative suspension systems and marine wave energy conversion set-ups.

2. Schedule of the research activities

First academic year (planned)

	Description	**Period**	**Activity abroad**
Literature review	According to our recent investigation on energy harvesting systems, a large number of methods for energy harvesting have been reported in the literature. Our first action will be to conduct a good literature review on energy harvesting methodologies and technologies for regenerative suspensions and wave energy systems, either for small size components or for large size components. Special attention will be paid on the recent works conducted by Casavola et al.	November 2022-March 2023 (5 months)	NO
Development of methods for optimal generation and control of the	After the literature review, we will focus on energy harvested due to road unevenness with different type of electromechanical actuators and roads. We will develop optimal control methods for improving the	April 2023-September 2023 (6 months)	NO

harvested energy in cars	quantity of the energy harvested from the suspension system while taking into consideration the ride comfort of passengers. Standard H_2 optimal control methods will be first investigated. Next, because the optimal solution is well known to be anticipative, aspects of preview control will be also considered and investigated. The mathematical study of the various electro-mechanical actuators used for such applications will be also conducted to identify the most convenient in terms of harvestable energy. At the end of this phase, I intend to write a review article.		

Second academic year (planned)

	Description	**Period**	**Activity abroad**
Development of methods for optimal generation and control of the harvested energy through Wave Energy Converters(WEC)	A 6-month visit to prof. David Angeli at Imperial College will give me the opportunity to study and investigate the potentialities of Model Predictive Control (MPC) and Economic Model Predictive Control (EMPC) in energy harvesting applications. EMPC is particularly well suited to optimize the performance under periodic regimes and these classes of strategies will be investigated for regenerative suspensions and wave energy systems. In many countries, there is sufficient wave energy to cater for the entire national demand. However, wave energy has not yet reached commercial viability, despite the first device designs being proposed in 1898. Control technology can play a major part in the drive for the economic viability of wave energy. We intend to optimize the Wave Energy Control and its use with other renewable energy sources. The mathematical study and the numerical simulations will be conducted. At the end of this phase, I intend to write an article.	January 2024-June 2024 - tentative (6 months)	YES tentative (at Imperial College London - Department of Electrical and Electronic Engineering)
Analysis of broadband energy harvester	The frequency spectrum of the input signal coming from the road unevenness or the wave is broad. Therefore, we intend to study an innovative electromagnetic actuator, e.g. by adding to the harvesting system more vibrating masses in order to capture the energy from different	April 2024-September 2024 (6 months)	NO

	frequencies. In the case of the car, this will be analyzed with the constraint that the ride comfort is maintained. The mathematical study and the numerical simulations will be conducted. At the end of this phase, I intend to write an article.		

Third academic year (planned)

	Description	**Period**	**Activity abroad**
Experimental investigation on prototypes	Construction of laboratory prototypes of wave energy systems and experimental investigation. Writing of an article.	October 2024 – March 2025	NO
Writing of the PhD thesis	Writing of the PhD thesis and its defense.	April 2025-October 2025	NO

3. Training and research activities plan

First academic year (planned)

	Description	Period	Final Exam	ECTS
A. Ph.D. courses	Linear algebra for control applications	Spring 2023	Yes	2
	Introduction to modeling, analysis and control of complex systems	January-February or June 2023	Yes	1
	Applied data-driven fault diagnosis	February-March 2023	No	1.5
	Hacking the control systems	January-February or July 2023	No	1.5
	Introduction to fault diagnosis and fault prognosis	March-April 2023	No	1.5
	Linear matrix inequalities in systems and control	April/May/June 2023	No	3
	Network dynamics and control	January-February or June 2023	No	3
	Safety vs security in risk based vehicle routing	To be defined	No	1.5
	Sustainable exploitation of renewable energy sources	To be defined	No	1.5
	Virtual constraints for mechanical systems	June-July 2023	No	1.5

	Learning influences in large scale dynamical social networks - a systems and control approach	March-July 2023	No	1.5
	Research Methodology		Yes	2
	Applications of MATLAB	June-July 2023	Yes	2
B. Master's degree courses	Industrial Automation and Optimal Control-Mod2: Optimal Control	March-May 2023	NO	3
C. Soft skill courses				
D. Participation to seminars				
E. Participation to international congresses or workshops	Industry 4.0 Fundamentals	January 2023		1
	TwinCaT 3 Engineering Course	Dates of next year under preparation		1
	Cycle of Seminars on Industry 4.0: Omron Electronics	Dates of next year under preparation		1
	Cycle of seminars on Industry 4.0: Digital Twin- Siemens and Masmec	Dates of next year under preparation		1
F. Presentation of research products at international congresses or workshops				
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			30
G. Individual research activity	Working principally in the Laboratory: Autonomous Systems Laboratory (LASA), University of Calabria	2022-2023 (at most 19 hours per week during 40 weeks approximately)		30
H. Supervision of students				
I. Integrative teaching activities				
J. Preparation of manuscripts				

for conferences or journals				
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			30
	TOTAL OF ECTS			60

Second academic year (planned)

	Description	Period	Final Exam	ECTS
A. Ph.D. courses				
B. Master's degree courses	Dynamical Systems Theory	October-December 2023	NO	4
	Vehicles Control - Mod1: Model Based Control Schemes	October – December 2023	NO	3
C. Soft skill courses				
D. Participation to seminars				
E. Participation to international congresses or workshops	Possible participation to an international conference			1
F. Presentation of research products at international congresses or workshops	Possible presentation of a work to international conference			1
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			9
G. Individual research activity	Working at the Imperial College	6 months (within 2024)		20
	Working in the Laboratory: Autonomous Systems Laboratory (LASA), University of Calabria	November-December 2024		20
H. Supervision of students				
I. Integrative teaching activities				
J. Preparation of manuscripts for	(Tentative) Preparation of conference paper and journal paper	2024		11

conferences or journals				
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			51
	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				
E. Participation to international congresses or workshops	Possible participation to an international conference			1
F. Presentation of research products at international congresses or workshops	Possible presentation of a work to international conference			1
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			2
G. Individual research activity	Working in the Laboratory: Autonomous Systems Laboratory (LASA), University of Calabria Thesis preparation	November-December 2024		43
H. Supervision of students				
I. Integrative teaching activities				
J. Preparation of manuscripts for conferences or journals	(Tentative) Preparation of conference paper and/or journal paper			15
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			58
	TOTAL OF ECTS			**60**