Advanced guidance, navigation, and control algorithms for space vehicles during atmospheric entry, descent, and landing maneuvers

Ph.D. candidate

Carlo BARBARA

Cycle

XL

Tutors

Prof. Carlo Novara

Prof. Giuseppe Calafiore

Dott. MassimilianoSaponara

1. Description of the research program

Guidance, navigation and control (GNC) algorithms during the Entry, Descent and Landing (EDL) maneuvers, are essential for the success of planetary exploration missions due to the difficult conditions of this phase.

The EDL include a lot of challenges and stringent constraints like high dynamics and uncertain environmental conditions, two aspects that complicate the deceleration control and the aerodynamic stability during the maneuvers.
The objective of this project is to develop a autonomous GNC real-time algorithm to achieve better autonomy, precision and robustness performances, without excessively increasing the computational cost.

The aim of the first part of the research program is to achieve the right skills and knowledge necessary to best approach research topics, studying the current state of the art and the latest research innovations, and following courses aimed at bridging some previous shortcomings about the research topics.

Then, the next step is to become familiar with EDL strategies, and develop the first algorithm prototypes in simpler nominal conditions, such as the absence of atmosphere and regular landing surfaces. In this phase will be useful being in touch with the Thales Alenia Space company, to speed up the learning of these topics and the techniques used.

Progressing, the focus of the research activity will be on the optimization of the trajectories and algorithms, from the point of view of computational cost, performance and robustness even in critical conditions.
For this step, an experience to the ESA European Space Research and Technology Centre (ESTEC) could be the best choice for the 6 month period abroad.

The final step of the program will be the testing and validation part of the algorithms, simulating theme in the real spacecraft's on-board CPU.

During all phases of the research, it would be very useful and stimulating to participate in seminars and conferences in the fields of automatic controls and aerospace, in order to always stay up to date and always find new ideas for the solutions to be implemented during the research.

2. Schedule of the research activities

First academic year(planned)

	Description	Period	Activity abroad
Insert name of first research activity	Study of the state of the art on EDL maneuvers and spacecraft systems of both the hardware part (sensors, actuators, CPU) and the navigation system. Preliminary development of autonomous EDL strategies in simpler nominal cases.	04/11/2024 31/03/2025	NO
Insert name of second research activity	Comparison of differentoptimization techniques for autonomous and real-time planning of trajectories in typical EDL maneuvers with focus on the landing phase.	01/04/2025 30/10/2026	NO

Second academic year(planned)

	Description	Period	Activity abroad
Insert name of first research activity	Development of innovative GNC algorithms for landing in extreme conditions with focus on autonomy and robustness (partially in Thales Alenia Space).	01/11/2025 30/04/2026 In company: 12/01/2026 10/04/2026	NO, activity partially with company, in Thales Alenia Space (Turin)
Insert name of second research activity	Development of innovative optimization techniques for trajectories of the EDL maneuvers, especially landing, to achieve performance and robustnessrequirements (noteasilyachievablesimultaneously).	01/05/2026 30/10/2026 Abroad: 01/09/2026 30/10/2026	YES, partially abroad, possibly to the ESA European Space Research and Technology Centre (ESTEC), Noordwijk,Netherlands.

Third academic year(planned)

	Description	Period	Activity abroad
Insert name of first research activity	Application of the developed algorithms to case studies of real interest (main focus on lunar landings). Montecarlo simulations.	01/11/2026 31/05/2027 Abroad: 01/11/2026 28/02/2027	YES, partially abroad, possibly to the ESA European Space Research and Technology Centre (ESTEC), Noordwijk,Netherlands.
Insert name of second research activity	Test and validation of the developed algorithms on simulations computer (partially in Thales Alenia Space).	01/05/2027 30/09/2027 In company: 03/05/2027 30/07/2027	NO, activity partially with company, in Thales Alenia Space (Turin)

3. Training and research activities plan

Ph.D. students are required to carry out activities for an amount of 60 ECTS (CFU) per year, for a total of 180 ECTS throughout the academic course. The activities carried out by Ph.D. students are divided into:

- **Didactic activities:** min 36 – max 60 ECTS (of the total 180 ECTS), preferably in the first two years of the course.
- **Research activities:** min 120 – max 144 ECTS (of the 180 total ECTS)

The ECTS related to the **didactic activity** can be obtained, for instance, by attending courses and seminars from graduate schools ormaster's degree programs. The DAUSY teaching-course catalogue (http://dausy.poliba.it/Ph.D./teaching-course-catalogue/) comprehends a list of didactic activities that can be included in this plan. Didactive activities are divided into:

A. **Ph.D. courses:**these are courses offeredat the Ph.D. level usually by doctoral schools (e.g., DAUSY Courses, PolibaScuDo Courses, SIDRA Summer School Courses, EECI IGSC Courses, Partner Universities Ph.D. Courses, etc.).
B. **Master's degree courses**:maximum 18 ECTS can be obtained by master's degree courses or single-cycle degree courses if these have not been attended by the Ph.D. student during his/her second level education.
C. **Soft skills:**maximum 12 ECTS can be obtained by courses classified as "soft skills" after the authorization of the Academic Board.
D. **Participation to seminars**:participation to seminars related to the research program is considered as a didactic activity (5 hours of seminar = 1.5 ECTS).
E. **Participation to international congresses or workshops**: participation at international congresses and workshops is considered as a didactic activity (1 international congress/workshop day = 1 ECTS).
F. **Presentation of research products at international congresses or workshops:** presentation of a research product at international congresses and workshops is considered as a didactic activity(1 presentation = 2 ECTS).

Note that:

- **At least 18 ECTS (of the total 180 ECTS) of didactic activities (A) and (B) must be obtained by completing a final exam**.
- For all courses (A) and (B) the 50% of the total course ECTS is recognized in case the final exam is not completed.
- Didactic activities must be confirmed with attendance certificates.

Examples:

- A 6-ECTS course, given in a master's degree course, can be attended by the Ph.D. student who can receive 3 ECTS if he/she does not complete the final exam (in this case the attendance must be certified).
- If a Ph.D. student attends a 5-day conference presenting a scientific contribution, he/she will obtain 5 ECTS for the participation and additional 2 ECTS for the conference contribution (the certification is required for both the attendance and the presentation).

Please refer to the*"Educational regulations of the Doctoral School of Politecnicodi Bari"* for more details
http://www.poliba.it/sites/default/files/dottorati/regscudopoliba.pdf

The ECTS related to the **research activities** are divided into:

G. **Individual research activity.**
H. **Supervision of students:**tutoring activities for students in undergraduate and master's degree programs.
I. **Integrative teaching activities:**supplementary teaching activity (e.g., seminars, courses, practical exercises, etc.) for students in undergraduate and master's degree programs within the limit of 40 hours per academic year.
J. **Preparation of manuscripts for conferences or journals.**

Note that each ECTS usually corresponds to 25 hours of research activity.

First academic year(planned)

		Description	Period	Final Exam	ECTS
A.	Ph.D. courses	Experimental modeling: model building from experimental data PhDSchool Politecnico di Torino	04/11/2024 05/12/2024	Yes	7
		Distributed/Decentralized Control and Optimization of Large-Scale Systems	28/01/2025 06/02/2025	Yes	1
		Non-integer order systems and controllers	04/02/2025 11/04/2025	Yes	1
		Introduction to autonomous systems	23/06/2025 30/06/2025	Yes	1
		ESA course: Fundamentals of Space Technology System and AOCS design for LEO and Gravity-monitoring satellites	05/2025 06/2025	Yes	3
B.	Master's degree courses				
C.	Soft skillcourses				
D.	Participation to seminars				
E.	Participation to international congresses or workshops	International Astronautical Congress (IAC) 2025	Early October 2025 (5 days)		5
		SIDRA Automation.it 2025	Early September 2026 (usually 3 days)		3
F.	Presentation of research products at international congresses or workshops				
		TOTAL OF ECTS FOR TRAINING ACTIVITIES			21
G.	Individual research activity	Research activity of the first year	11/2024 10/2025		30
H.	Supervision of students				
I.	Integrative teaching activities	Exercitations course Nonlinear control and aerospace applications (Politecnicodi Torino)	03/2025 06/2025		1
J.	Preparation of manuscripts for conferences or journals	Preparation of manuscripts for conferences (and eventually for journals later)	Second half of first year		8
		TOTAL OF ECTS FOR RESEARCH ACTIVITIES			39
		TOTAL OF ECTS			**60**

Second academic year(planned)

		Description	Period	Final Exam	ECTS
A.	Ph.D. courses	Other DAUSY or PoliBaScudo courses	tbd	tbd	tbd
B.	Master's degree courses	Convex optimization and engineering applications(Politecnicodi Torino)	10/2025 01/2026	Yes	6
		Optimization for machine learning (Politecnicodi Torino)	10/2025 02/2026	Yes	6
C.	Soft skill courses				

	Description	Period	Final Exam	ECTS
D. **Participation to seminars**				
E. **Participation to international congresses or workshops**	International AstronauticalCongress (IAC) 2026	Early October 2026 (usually 5 days)		5
	SIDRA Automation.it 2026	Early September 2026 (usually 3 days)		3
F. **Presentation of research products at international congresses or workshops**	Present research material at IAC 2026	Early October 2026 (usually 5 days)		2
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			22+
G. **Individual research activity**	Research actiivity of the second year	11/2025 10/2026		28
H. **Supervision of students**	Supervision for students course Nonlinear control and aerospace applications (Politecnicodi Torino)	03/2026 06/2026		1
I. **Integrative teaching activities**	Exercitations course Nonlinear control and aerospace applications (Politecnicodi Torino)	03/2026 06/2026		1
J. **Preparation of manuscripts for conferences or journals**	Preparation for manuscripts on the PhD topics for conferences and journal			8
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			38
	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**	Some soft skill course	tbd	tbd	tbd
D. **Participation to seminars**				
E. **Participation to international congresses or workshops**	Participation to some congress			4
F. **Presentation of research products at international congresses or workshops**	Presentation of research work to some congress			2
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			6+
G. **Individual research activity**	Research activity of the third year	11/2026 08/2027		32
	PhD thesis preparation	04/2027		10

			10/2027		
H.	**Supervision of students**	Supervision for students course Nonlinear control and aerospace applications (Politecnicodi Torino)	03/2027 06/2027		1
I.	**Integrative teaching activities**	Exercitations course Nonlinear control and aerospace applications (Politecnicodi Torino)	03/2027 06/2027		1
J.	**Preparation of manuscripts for conferences or journals**	Preparation for manuscripts on the PhD topics for conferences and journal	11/2026 08/2027		10
		TOTAL OF ECTS FOR RESEARCH ACTIVITIES			54
		TOTAL OF ECTS			**60**

Carlo Barbara

_____

Prof. Carlo Novara

_____

Prof. Giuseppe Calafiore

_____

Dott. Massimiliano Saponara

_____