NATIONAL PH.D. PROGRAM IN AUTONOMOUS SYSTEMS

Risk-aware control of aerial cargo drones

Ph.D. candidate

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Cycle

XXXIX

Tutors

Professor Karl von Ellenrieder

1. Description of the research program

There are several applications where the use of a cargo drone can reduce costs, energy consumption and emissions while improving safety and operational efficiency. Representative sectors that can take advantage of this include telecommunications, logistics, energy, agriculture and forestry. The goal is to make advances in control and trajectory planning, which are critical to operational safety, as a drone and its pilot can work cooperatively across a wide range of missions.

The research will develop a comprehensive approach by leveraging the latest advances in nonlinear control, trajectory planning and reactive collision avoidance to improve the use of cargo drones in diverse applications. The goals include the development of:

(a) mission models that take into account the risks presented by operational and environmental conditions;

(b) semi-automatic and automatic control algorithms to reduce drone operator burden and improve safety;

(c) algorithms for risk-aware trajectory planning;

(d) algorithms for reactive collision safety control.

The methods developed will be validated through experiments performed in collaboration with FlyingBasket Srl. of Bolzano.

The main research question to be addressed is: “Can we improve the safety and efficiency of cargo drones through semi-automatic control?”. To address this question, the following topics will be explored:

1) Dynamic models;

2) Robust control algorithms;

3) Safety-critical control;

4) Trajectory planning algorithms;

5) Experimental testing and system integration - Experiments will be performed to validate the developed algorithms and ensure that the controllers and planners are integrated. The stable mixing of signals from the human and the automatic controller is one of the most challenging aspects.

Schedule of the research activities

First academic year (planned)

	Description	Period	Activity abroad
Dynamic modeling	The initiative requires physical models of the drone, tether, cargo, and propulsion system. The models will be developed as part of a simulation that will include external disturbances and will be validated/recalibrated with experimental tests.	November 2023 – March 2024	No
Experimental testing	Tests aim at the validation and recalibration of the dynamic models.	February 2024 – March 2024	No
Robust control algorithms	The control algorithms used must be robust to large dynamic changes in the vehicle. The "higher order sliding mode" control approach will be examined.	March 2024 – July 2024	No

Second academic year (planned)

	Description	Period	Activity abroad
Safety-critical control	Since the safety of a drone system is critical, the use of a safety controller can be of great benefit. This new technique can ensure collision-free flight, allowing the configuration of the drone to be changed without rearranging the controller.	September 2024 – December 2024	No
Trajectory planning algorithms	Algorithms should minimize the risk of collisions between the drone/load and obstacles, as well as the possibility of the drone/load assuming unsafe situations. Planning will also take into account energy consumption to maximize operational time.	November 2024 – April 2025	Yes 6 months at the University of Southern California
Experimental testing	Tests aim at the validation of controllers and algorithms developed in the previous months.	March 2025 – June 2025	No

Third academic year (planned)

	Description	Period	Activity abroad
Shared human-machine control	In shared human-robot control, the robot operates semi-autonomously and the challenge is to combine the inputs from the human and from the automatic control system.	September 2025 – February 2026	No
Experimental testing	Tests aim at the validation of controllers and algorithms developed in the previous months.	January 2026 – April 2026	No

2. 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 or master'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 offered at the Ph.D. level usually by doctoral schools (e.g., DAUSY Courses, Poliba ScuDo 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 Politecnico di 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	Intelligent control system	Jan 2024 - Feb 2024	Yes	2
	Introduction to optimal linear quadratic control	Feb 2024 - Mar 2024	Yes	2
	Human autonomous systems interaction	Mar 2024 - Apr 2024	Yes	1
	Control of marine vehicles	Jun 2024 – Jul 2024	Yes	3
	Optimization via Extremum Seeking	Jun 2024 – Jul 2024	Yes	1
B. Master's degree courses				
C. Soft skill courses	Advanced scientific English	Nov 2023 - Feb 2024	No	3
	Theory of scientific method	Nov 2023 - Feb 2024	No	4
D. Participation to seminars	Safety VS security in risk-based vehicle routing		No	1.5
	Complex systems modeling		No	1.5
E. Participation to international congresses or workshops	EECI modules	May 2024 - Jun 2024	No	3
F. Presentation of research products at international congresses or workshops				
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			
G. Individual research activity	Dynamic modeling, testing, control algorithms	Nov 2023 – July 2024	No	30
H. Supervision of students				
I. Integrative teaching activities	Assistant to robotics lectures and courses	Mar 2024 – Jul 2024	No	4

J. Preparation of manuscripts for conferences or journals	Manuscript related to robust control of cargo drones	Mar 2024 – Jul 2024	No	4
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			38
	TOTAL OF ECTS			**60**

Second academic year (planned)

	Description	**Period**	**Final Exam**	**ECTS**
A. Ph.D. courses	Courses related to robust control, non-linear control, trajectory planning	Nov 2024 – Jul 2025	Yes	9
B. Master's degree courses				
C. Soft skill courses				
D. Participation to seminars	Seminars offered by DAUSY		No	3
E. Participation to international congresses or workshops	Summer schools (EECI, SIDRA)		No	6
F. Presentation of research products at international congresses or workshops				
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			
G. Individual research activity	Safety-critical control and trajectory tracking	Nov 2024 – Jul 2025	No	33
H. Supervision of students				
I. Integrative teaching activities	Assistant to robotics lectures and courses	Mar 2025 – Jul 2025	No	4
J. Preparation of manuscripts for conferences or journals	Manuscript related to safety-critical trajectory tracking of cargo drones	Feb 2025 – Jul 2025	No	5
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			42
	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	Seminars offered by DAUSY		No	3
E. Participation to international	Participation to workshops on autonomous systems and control		No	3

	congresses or workshops				
F.	**Presentation of research products at international congresses or workshops**	Presentation of works related to robust shared-human control of cargo drones	Nov 2025 – May 2026	No	3
		TOTAL OF ECTS FOR TRAINING ACTIVITIES			
G.	**Individual research activity**	Human-machine shared control Writing of the thesis	Nov 2025 – Nov 2026	No	43
H.	**Supervision of students**	Supervision of students writing the master thesis	Feb 2026 – Jul 2026	No	4
I.	**Integrative teaching activities**				
J.	**Preparation of manuscripts for conferences or journals**	Manuscript related to human-machine shared control of cargo drones	Dec 2025 – May 2026	No	4
		TOTAL OF ECTS FOR RESEARCH ACTIVITIES			51
		TOTAL OF ECTS			**60**

3. List of the publications written by the candidate in the triennium

Insert the list of papers written during the Ph.D. program. If the paper is still not published indicate its status (e.g., submitted, under review, under 2nd review round, accepted to appear, etc.).

International Journal Articles

To be determined

International Conference Proceedings

To be determined

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