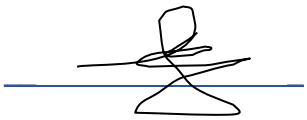
PhD in Information Technology and Electrical Engineering
Università degli Studi di Napoli Federico II

PhD Student:

Cycle: XXXVII

Training and Research Activities Report

Academic year: 2022-23 - PhD Year: Second



Tutor: prof. Vincenzo Lippiello *tutor signature*

Date: October 21, 2023

Training and Research Activities Report

PhD in Information Technology and Electrical Engineering

Cycle: XXXVII **Author: Julien Mellet**

1. Information:

- **PhD student: Julien Mellet** **PhD Cycle: 37th**
- **DR number: 155251**
- **Date of birth: 15/08/1994**
- **Master Science degree: Engineering: Navigation, Guidance & Control**
  University: Northwestern Polytechnical University, Xi'an, China
- **Scholarship type: European Union fund with AERO-TRAIN project under the Horizon 2020 Research and Innovation Program and within the Marie Skłodowska-Curie (MC) Innovative Training Network (ITN), with Grant Agreement No 953454**
- **Tutor: Prof. Vincenzo Lippiello**

2. Study and training activities:

Activity	Type[1]	Hours	Credits	Dates	Organizer	Certificate[2]
Neural Network for State Estimation application & beginning of Omnidirectional Micro Aerial Vehicle control with haptic feedbacks	Research		10	1.01.2023 – 31.12.2023		N
Training School 3 of AERO-TRAIN project on Autonomous Aerial Field Robotics | Lulea, Sweden	Course	28	2	5.12.2023– 9.12.2023	George Nikolakopoulos, LTU, Chair Professor	Y
Is control a solved problem for aerial robotics research? By Prof. Antonio Franchi	Seminar	1	0.2	7.02.2023	Ph.D Fabio Ruggiero, UNINA	Y
Development of an aerial manipulation haptic feedback setup with augmented virtuality	Research		7.8	01.01.2023 – 28.02.2023		N
First Integration Week of AERO-TRAIN project | Tampere University, Finland	Course	28	2	20.03.2023 – 24.03.2023	Dr. Erdem Sahin & Prof. Atanas Gotchev	Y

Development of an aerial manipulation control system with haptic feedback setup in augmented reality	Research		7.8	01.03.2023 – 30.04.2023		N
AI, Rbot and Society: Challenges and Opportunities for Social Innovation – Dr. Amit Kumar Pandey	Seminar	1	0.2	25.05.2023	Prof. Bruno Siciliano	Y
Exploring Advanced Aerial Robotics: A Journey into Cutting-Edge Projects and Neural Control – Eng. Eugenio Cuniato	Seminar	1	0.2	29.06.2023	Engr. Julien Mellet	Y
Inspection-based robotics for society - Advanced Center for Aerospace Technologies (CATEC)	Seminar	2.5	0.5	15.06.2023	Dr. Antidio Viguria Jiménez	Y
Migration of legacy IT infrastructures into the cloud: approaches and strategies	Seminar	2	0.4	23.05.2023	Prof. Roberto Canonico, UNINA	Y
Writing of a paper on control of an omnidirectional drone with haptic feedback and mixed reality visualization.	Research		9.1	01.05.2023 – 30.06.2023		N
Writing of a paper on control of an omnidirectional drone with haptic feedback and mixed reality visualization.	Research		10	01.07.2023 – 31.08.2023		N
2nd Integration Week (IW2) held at Eurecat Cerdanyola	Course	28	2	3.07.2023 – 6.07.2023	Julián Cayero & Daniel Serrano, Eurecat	Y
IEEE Authorship an Open Access Symposium: Tips	Seminar	1.5	0.3	20.09.2023	Rachel Berrington	Y

and Best Practices to Get Published from IEEE Editors					Director, IEEE Client Services	
Writing of a paper and editing video complementary material on control of an omnidirectional UAV with haptic feedback and mixed reality visualization. Publication of neural estimation paper	Research		7.3	1.09.2023 – 31.10.2023		N

1) Courses, Seminar, Doctoral School, Research, Tutorship
2) Choose: Y or N

2.1. Study and training activities - credits earned

	Courses	Seminars	Research	Tutorship	Total
Bimonth 1	**0**	**0**	**10**	**0**	**10**
Bimonth 2	**2**	**0.2**	**7.8**	**0**	**10**
Bimonth 3	**2**	**0**	**8**	**0**	**10**
Bimonth 4	**0**	**1.3**	**9.1**	**0**	**10.4**
Bimonth 5	**0**	**0**	**10**	**0**	**10**
Bimonth 6	**2**	**0.3**	**7.3**	**0**	**9.6**
Total	**6**	**1.8**	**52.2**	**0**	**60**
Expected	**30 - 70**	**10 - 30**	**80 - 140**	**0 – 4.8**	

3. Research activity:

General:

This research aims to develop a control framework for a single operator to pilot a team of aerial manipulators with haptic feedback. Using multiple drones allows for lifting larger payloads but increases control complexity. The primary goal is to reduce the complexity of the pilot inputs needed to control the semi-autonomous system. The research explores strategies for aerial manipulations with haptic and visual augmentation. The final objective is to create a multimodal framework that enables a single operator to control multiple aerial robots for telemanipulation. Additionally, the research seeks to understand the impact of haptic feedback on the operator's performance during aerial manipulation tasks. This year focuses is on one omnidirectional vehicle conducting aerial physical interactions in a mixed reality environment with force feedback.

Progress towards expected results:

A visiting period has been done at the Autonomous System Lab (ASL) – ETH, Zurich. A multimodal bilateral teleoperation framework has then been proposed to control their omnidirectional aerial platform (OMAV). It has been a matter first, to give 3D vision to the operator with Mixed Reality (MR) goggles,

then, sense of touch through a haptic feedback joystick. Because the aforementioned state-of-the-art teleoperation system is quite a recent tool, no system evaluation has been done. I thus carried out a Taguchi experiment design to find optimal parameters (*Haptic vs. non-haptic, 3D visions vs. 2D vision, experienced operator vs. beginner*) to improve operator dexterity. Considering the described gap, my research contributions are *(i) the design of a dedicated MR and haptic feedback for 6DoF (Degrees of Freedom) teleoperation, (ii) a qualitative evaluation of the proposed framework in centimetres-level-accuracy demanding interaction tasks, and (iii) a qualitative evaluation of operator performance in extensive user study.*

We pursued a minimal sensor setup for cable-suspended transport using a multi-rotor. Traditional model-based estimators lack precision and require predefined parameters. Instead, we employed a supervised neural network for position estimation and trained it in a simulated environment with domain randomization. This network demonstrated zero-shot generalization for load position estimation, even with not previously seen perturbations. This approach validated real-time position estimation of a cable-suspended end-effector using only onboard inertia sensors on a standard quadrotor.

Finally, participation in a Training School (TS) and several Integration Weeks (IW) *(part of the current European project involvement)* allowed me to deploy current engineering knowledge on a real-world application. Especially, it has first been a matter to deploy a target detection algorithm. The goal is to find and estimate the position of the aimed target location. The state-of-the-art YOLOv4 has been used, coupled with point clouds normal extraction. It is secondly a matter to propose a robot arm for the task. A compliant mechanism has been proposed. It combines high energy passive dissipation with 2DoF actuation. Its actuation unit is deported from its kinematic link to ensure low inertial disturbance on the aerial platform.

Currently, no issue has been noticed to reach the proposed research.

4. Research products:

a. *MR+Haptic Control Framework (prototype):* During the visiting period abroad, a bilateral control framework has been developed. It allows 6DoF control with haptic feedback of an aerial robot. A user study was designed and approved by ethical committee of ETH, Zurich. It involved 28 participants, including 14 trained at using the setup for 2 months.
b. *Compliant Robot Arm Aerial Physical Interaction (prototype):* For the Grand Challenge competition of the AERO-TRAIN project, a new robot arm has been developed. A non-expensive lightweight compliant mechanism has been proposed to comply to the technical needs and the rules imposed by the organizers. It combines high energy dissipation with 2DoF actuation to compensate for the lack of accuracy of flat multirotor.
c. *Neural State Estimation of a Cable Suspended Payload (conference paper):* There is a weight obsession for aerial vehicles, especially for transportation where each gram saved on the platform is a gram that can be added to the payload. By considering a minimal sensing quadrotor, we proposed a neural network to estimate load position. Using proprioceptive sensors has been shown sufficient to perform accurate pick-and-place, while feeding the controller with.

The conference paper has been accepted to the International Conference on Informatics in Control, Automation and Robotics (ICINCO) 2023, and is finalist for best paper overall award.

5. Conferences and seminars attended

No conference attended

6. Periods abroad and/or in international research institutions

- ***TS3: Training School 3 of AERO-TRAIN project on Autonomous Aerial Field Robotics, Lulea, Sweden:*** For a period of one week, inside the ITN AERO-TRAIN project is has focus on the field experimental actives, such as designing and planning an experiment, sensor configurations, and data collection, processing, and analysis. The training program also exposed ESR's (Early-Stage Researchers) with the practical aspects of estimation, computer vision and perception algorithms.
- ***IW1: First Integration Week of AERO-TRAIN project, Tampere University, Finland:*** This period of one week focused on Human-Robot Interfaces (HRI). The lectures provided knowledge on the fundamentals of 3D scene capture, representation, processing, and visualization along with the related algorithms and methods. Presentation of this technologies has then followed. Finally, integration of the aerial platforms with indoor localization system has been performed.
- ***IW2: Second Integration Week of AERO-TRAIN project, Eurecat, Cerdanyola:*** This week revolved around navigation, target detection and target contact in GNSS denied environment. Unlike IW1, the new integration will need of on-board sensors to feedback the localization to the control algorithms, not only on the target approach phase, but also to move the drone from point A to point B, avoiding obstacles. Aerial platforms performed inside an underground parking lot, as well as on a train tunnel.
- ***Secondment Period Abroad, ASL-ETH Zurich, Switzerland*** *(Supervised by M. Tognon & R. Siegwart)**:*** For a period of 5 months and 1 week, it has been a matter to focus on haptic feedback and MR for aerial manipulation. The system has first been developed in a simulated environment. Then real-world experiments have been done showing centimetric accuracy. Finally, a user study evaluated the impact of vision, haptic feedback and user experience at using this kind of system.

A total of *six months* has been spending abroad this year.

7. Tutorship

No Tutorship

8. Plan for year three

The third PhD year will focus at integrating the previously developed prototypes in the overall system. International collaboration should continue for two reasons: access to design of experiment expertise and access to research facilities not available at the host institution. The research directions will be,

- **Neural Estimator:** Extension work on previously published ICINCO23 paper on generalization of neural estimation for external wrench estimation plus a comparison with state-of-the-art external observer.
- **OMAV Design;** Propose and study a novel omnidirectional micro aerial vehicle (OMAV) for 6DoF aerial manipulation.
- **Multi-Robots for Aerial Teleoperation:** Implement bilateral teleoperation theory for multi-robot system. Comparative study at using tether flat quadrotors versus fully attached OMAV.