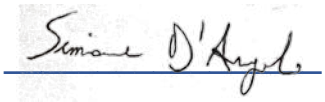
PhD in Information Technology and Electrical Engineering
Università degli Studi di Napoli Federico II

PhD Student: D'Angelo Simone

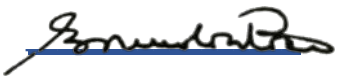
Cycle: XXXVII

Training and Research Activities Report

Academic year: 2022-23 - PhD Year: Second



Tutor: prof. Bruno Siciliano



Co-Tutor:

Date: October 31, 2023

1. Information:

- **PhD student:** D'Angelo Simone **PhD Cycle:** XXXVII
- **DR number:** DR995858
- **Date of birth:** 01/07/1996
- **Master Science degree:** Automation Engineering **University:** Federico II of Naples
- **Scholarship type:** DIETI
- **Tutor:** Prof. Bruno Siciliano
- **Co-tutor:**

2. Study and training activities:

Activity	Type[1]	Hours	Credits	Dates	Organizer	Certificate[2]
Game Theory for Information Engineering	seminar	3	0.6	13/12/22	Prof. Marcello Caleffi	y
From Cyber Situational Awareness to Adaptive Cyber Defense: Leveling the Cyber Playing Field	seminar	2	0.4	13/12/22	Prof. Giancarlo Sperlì	y
Cybercrime and Information Warfare: National and International Actors	seminar	2	0.4	18/11/22	Prof. Simonpietro Romano	y
-Study on already published works about aerial manipulation, visual servoing and force control. -Study on PX4-autopilot firmware for PixHawk. -Implementation of visual servoing algorithms on omnidirectional aerial vehicle -Implementation of	research			From 1/11/22 To 31/12/22		

parallel vision/force control algorithms on aerial manipulator -Tests in simulations -Laboratory activity						
Using Deep Learning properly	Ad Hoc course		0	10-12-17-19-24/01/2023	Prof. Andrea Apicella	n
Industry 4.0 Fundamentals in Bosch Applications	Seminar	10	2	January 23-26, 2023	Eng. Martino Bruni, Prof. Ing. Mariagrazia Dotoli, Ph.D.	y
Is control a solved problem for aerial robotics research?	Seminar	1	0.2	12/01/23	Prof. Antonio Franchi, Prof. Fabio Ruggiero	y
NDT in contesto aeronautico	Seminar	1	0.2	17/02/23	Prof. Carlo Forestiere, Ing. Giovanni Gravina	y
Multi robot control of heterogeneous herds	Seminar	1	0.2	16/02/23	Prof. Montijano	y
-Study on already published works about aerial manipulation, visual servoing and force control -Study and rework on PX4-autopilot firmware for PixHawk and ROS2 -Study on Image elaboration techniques woth deep learning library YOLO -Prepared and Submitted paper to ICUAS Conference -Tests in Flight arena with new tilting drone -Laboratory activity	Research		7.4	From 01/01/23 To 28/02/23		

Model Predictive Control	Course		4	3/5/12/14/17/24/28-04-2023 – 2/3/5-5-2023	Prof. Alberto Bemporad – Scuola IMT Alti Studi Lucca	y
From Romeo & Juliet to OceanOne Deep-Sea Robotic Exploration	seminar	1	0.2	23/03/23	Prof. Siciliano & Prof. Khatib	y
-Study on already published works about aerial manipulation, visual servoing and force control -Study on ROS2 and bridge communication with ROS1 -Study and rework on PX4-autopilot firmware for PixHawk and ROS2 -Application of Image elaboration and visual servoing techniques on real hardware -Tests in Flight arena with new tilting drone -Laboratory activity	research		9.8	From 01/03/23 To 31/04/23		
2023 Spring School in Transferable Skills	course		2	May, 24-25	Federico II	y
Ai, Robots and society: challenges and opportunities for social innovation	seminar	1	0.2	25/05/23	Prof. Siciliano & Dr.. Pandey	y
Robotic Spacecraft Rendezvous with a Tumbling Target for Capture Robust Methods for Planning and Control	seminar	1	0.2	11/05/23	Prof. Siciliano & Dr.. Lampariello	y
Exploring Advanced Aerial Robotics: A journey into cutting-	seminar	1	0.2	29/6/23	Eng. Cuniato	y

edge projects and neural control						
-Study on ROS2 and bridge communication with ROS1 -Development of custom PX4-autopilot firmware for PixHawk -Tests in Flight arena with tilting drone -Laboratory activity	research		1.8	From 1/05/23 To 30/06/23		
Field and Service Robotics	tutorship		1.6	From 06/03/23 To 9/06/23	Prof. Fabio Ruggiero	
-Projecting and building new mini tilting drone. -Study on ROS2 and bridge communication with ROS1 -Study on interfacing ROS2 and PX4 flight control stack -Development of ROS2 controller for aerial manipulator -Development of custom PX4-autopilot firmware for PixHawk -Tests in Flight arena with new tilting drone Laboratory activity	Research		6	From 1/07/23 To 31/08/23		
Semantic artifacts and multimedia knowledge graphs for biodata integration	course	10	2	12-13-18-20/09-09/10	Prof. Cristiano Russo	y
Formazione sulla progettazione europea offerta dalla Direzione Generale della Ricerca del Ministero dell'Università e della Ricerca nell'ambito	course	17	3.4	14/09-28/09-12/10-26/10-09/11-23/11		y

del PON Ricerca e Innovazione						
IEEE Authorship and Open Access Symposium: Tips and Best Practices to Get Published from IEEE Editors	seminar	1.5	0.3	20/09/23	ieeexplore	y
-Testing new mini tilting drone. -Preparing paper for ISER conference -Complete review process for RAS accepted paper -State of the art study on model predictive control techniques to control tilting drones -Continue working on parallel vision/force control -Started implementing optimization problem to control interaction with the environment -Study on contact model and friction modelling	research		8.3	From 1/09/23 To 31/10/23		

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**	**1.4**	**8.6**	**0**	**10**
Bimonth 2	**0**	**2.6**	**7.4**	**0**	**10**
Bimonth 3	**0**	**0.2**	**9.8**	**0**	**10**
Bimonth 4	**6**	**0.6**	**1.8**	**1.6**	**10**
Bimonth 5	**0**	**0**	**6**	**0**	**6**
Bimonth 6	**5.4**	**0.3**	**8.3**	**0**	**14**
Total	**11.4**	**5.1**	**41.9**	**1.6**	**60**
Expected	**30 - 70**	**10 - 30**	**80 - 140**	**0 – 4.8**	

3. Research activity:

The main research activity involves studying, designing, and implementing of solutions to handle the interaction between aerial autonomous systems and the environment. The focus is on unmanned aerial manipulator which are composed of an autonomous aerial vehicle equipped with a robotic arm; different sensors are considered to retrieve feedback and info from the environment.

In the following, the results and some ongoing activities carried out during the first two years of PhD are presented and discussed. In the end, some ideas for future works are provided. The activities focus on studying and applying different state-of-the-art and new approaches to control the interaction of autonomous systems with known/unknown environments.

Past research activities

Control of Hybrid aerial/ground manipulator for inspection based task

Control and modelling of a hybrid robot composed of an aerial platform equipped with a hyper-redundant snake-like arm and four fixed wheels as part of the Hyfliers project. The activity investigates the problem of controlling a wheeled mobile manipulator endowed with a snake-like arm to inspect the structures while stabilizing the supporting pipe. The whole project can be divided into the following sub-activities:

- manipulator kinematic and dynamic modelling employing the screw theory approach.
- model prediction control (MPC) implementation employing the snake-like arm dynamic to stabilizethe aerial platform on the landing pipe when the wheel torques saturate.
- collision-free trajectory planning and development of collision and self-collision avoidance algorithms.
- parallel force-motion manipulator control definition with a prioritized redundancy resolution scheme.

When the wheel torques saturate, the stabilization task leverages the resulting propagating force on the wheeled robot given by the snake-like arm's dynamics. Different contributions are projected in the null space of the Jacobian matrix to be executed simultaneously. Simulation in Gazebo physics engine proves the performance of the developed control law.

The results are presented in the already published journal paper **Stabilization and Control on a Pipe-Rack of a Wheeled Mobile Manipulator with a Snake-like Arm**.

Control of Aerial Robot to install bird diverter

In this work, we propose a preliminary control framework for the autonomous installation of clip bird diverters on high-voltage lines as part of the Aerial Core project. The idea was born as a first attempt to use and modify the Pixhawk firmware in a real-scenario case study. The custom firmware is developed in Simulink with the UAV Toolbox Support Package for PX4 Autopilots. The Embedded Coder directly converts the Simulink model into a module compiled and integrated with the PX4 executable. The installation process is achieved by combining the Geometric Tracking Control on SE(3) and an admittance filter to adjust the linear position references to be compliant

with the interaction spot. The results have been validated in both simulation and real-world experiments through a drone equipped with a sensorized stick. This last successfully inserted the bird diverter device on a mock-up structure with minimal disturbances on the aerial platform. The system has been presented in the paper **Development of a Control Framework to Autonomously Install Clip Bird Diverters on High-Voltage Lines**.

Interaction Control of Omnidirectional Tilting Drone

This project focuses on controlling an aerial manipulator composed of an omnidirectional tilting drone equipped with a five-degrees-of-freedom robotic arm. The robot has to interact with the environment to inspect structures and perform non-destructive measurements. The omnidirectional drone is controlled through a custom version of the PX4 firmware allowing the control of the tilting angles. The end-effector is provided with a force sensor and an ultrasonic sensor. A parallel position-force control technique is developed to establish contact with the designed surface with a desired force profile. An echometer sensor is mounted at the end-effector tip to measure the thickness of the interaction surface. Successive measures are performed to show the repeatability of the algorithm. The experiments are presented in the paper **Development of a semi-autonomous framework for NDT inspection with a tilting aerial manipulator**, already accepted at 18th International Symposium on Experimental Robotics.

Current Research Activity

Control of Omnidirectional Tilting Drone Performing Push-&-Slide Inspection tasks

This activity investigates the problem of controlling a tilting unmanned aerial vehicle (UAV) endowed with a robotic manipulator to complete inspection tasks in unknown environments. The works focus on the possibility of merging different sensors' feedback to control the robot. A parallel force/vision control algorithm has been developed to drive the aerial manipulator toward an unknown object. The robot is equipped with a camera system to both navigate the unknown environment and detect a tag which represents the inspection spot. Using the image features combined with the interaction force feedback the objective is to complete push-and-slide inspections.

The task is executed in quasi-stationary flight conditions and the two systems are seen as decoupled: while the aerial platform keeps the fixed position with respect to the detected tag, the manipulator completes the planned inspection. The whole architecture will be tested in both simulated and real-scenario environments.

Customization of Pixhawk firmware

Pixhawk is one of the most used flight controllers in the aerial robotics research field. It provides different capabilities and flight modalities to control different drone shapes. This activity modifies its standard control stack to include a fully customizable control template. The idea is to add new flight modalities triggering custom controllers. The PX4 flight stack can already be modified by developing Simulink or ROS/ROS2 controller nodes, but it is needed to stop some functionalities and safety layers.

The proposed solution allows the user to switch between different control techniques, preserving the standard flight stack and safety procedures. The custom firmware can be used both with flat and tilting drones, in a custom "position" (sending setpoint through the radio controller) and a custom "offboard" (planning a trajectory in ROS or ROS2) flight modes.

Drones Customization

Practical activity focused on design and on customize drones for testing purposes.

Ideas for future works

Following up on the current activities, it is possible to define ideas for future works.

Investigating Optimization-based Technique for the Interaction Control

The work goal is to develop a strategy to perform inspection-based tasks solving an optimization problem. Classic control approaches, already investigated, cannot ensure the fulfilment of constraints during the interaction. An important aspect to consider during the interaction with the environment isthe friction generated between the interaction surface and the end-effector tip. The idea is to develop a model predictive controller capable of computing the desired command for an aerial manipulator to perform a push-and-slide task. The control inputs are computed to preserve the stable contact in each control loop. In general, by defining a Coulomb Friction Cone, conditions on the contacts' stability can be retrieved: stability is ensured if the vector lies inside the defined cone. Controlling this vector to the boundary of the cone it will be possible to preserve the contact and allow the sliding on the surface while avoiding slippery conditions. These conditions can be modelled as friction constraints in the MPC formulation.

PX4 customization with different control strategies

As possible extensions on the PX4 firmware customization activity, it will be the development of new firmware capabilities: the possibility of handling feedback from force sensors connected directly to the board and the development of specialized control action capable of controlling the interaction with the environment will be investigated. The developed template and custom control modalities allow the introduction of model-based controllers.

4. Research products:

Scientific paper: **Development of a Control Framework to Autonomously Install Clip Bird Diverters on High-Voltage Lines**
Authors: ***Simone D'Angelo***, *Francesca Pagano, Fabio Ruggiero, Vincenzo Lippiello*
Conference: *The 2023 Int´L Conference On Unmanned Aircraft Systems* **- ICUAS 23**
Current state: **published**

Scientific paper: **Stabilization and Control on a Pipe-Rack of a Wheeled Mobile Manipulator with a Snake-like Arm**
Authors: ***Simone D'Angelo***, *Antonio Corrado, Fabio Ruggiero, Jonathan Cacace, Vincenzo Lippiello*
Journal: **Robotics and Autonomous Systems (RAS)**
Current state: **published**

Scientific paper: **Development of a Semi-Autonomous Framework for NDT Inspection with a Tilting Aerial Platform**
Authors: *Salvatore Marcellini*, ***Simone D'Angelo***, *Alessandro De Crescenzo, Michele Marolla, Vincenzo Lippiello, and Bruno Siciliano*
Conference: *18th International Symposium on Experimental Robotics* - **ISER 2023**
Current state: **accepted**

Student contest: **Leonardo Drone Contest**
Organized by Leonardo S.p.A.

5. Conferences and seminars attended

Conference Attended: *The 2023 Int´L Conference On Unmanned Aircraft Systems* - **ICUAS 23 | June 6-9, 2023 | Lazarski University, Warsaw, Poland**
Paper presented: **Development of a Control Framework to Autonomously Install Clip Bird Diverters on High-Voltage Lines** - (***Simone D'Angelo***, *Francesca Pagano, Fabio Ruggiero, Vincenzo Lippiello)*

6. Periods abroad and/or in international research institutions

7. Tutorship

Tutor of the course Field and Service Robotics, spring semester: University of Naples "Federico II". Master's Course in Automation Engineering (Second year, second semester 06/03/2023 – 09/06/2023)

8. Plan for year three

The third year of PhD will be a fundamental step to finalize the pending activity and retrieve the needed results. As discussed in the previous sections, the idea will be to study and develop optimization-based techniques to control and handle the interaction with the environment.

Optimal control satisfies the definition of constraints during the whole task execution. Dynamic constraints do not include only the system dynamic model but also friction constraints and contact stability constraints. The performance of an interaction control law also relies on the dynamic properties of the interaction surfaces: friction plays a crucial role in automatic controls; it affects the stability, accuracy, and efficiency of systems. Its management is essential to avoid unwanted oscillations, improve dynamic response, and reduce energy losses in controlled systems, especially in mechanical applications where responsiveness and efficiency are crucial.

The period abroad will be divided into two different parts. The PRISMA Lab started a new project in collaboration with the Toronto Metropolitan University on developing solutions for NDT inspection with unmanned aerial vehicles. The project requires a student exchange for two months. Another possibility is to spend the remaining time in Seville (Spain) to work with the research group of Prof. Ollero.

The thesis topic will be focused on the activity carried out during the research activity at PRISMA Lab with a connection to the new topics studied during the future period aboard. Aerial robots will be the subject of the thesis, with their applications and different controllers, including a comparison between the different solutions proposed.