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

PhD Student: Giancarlo D'Ago

Cycle: XXXVII

Training and Research Activities Report

Academic year: 2022-23 - PhD Year: Second

Giancarlo D'Ago

Tutor: Prof. Fabio Ruggiero

Fabio Ruggiero

Co-Tutor: Dr. Eng. Luca Rosario Buonocore
Prof. Vincenzo Lippiello

Date: December 12, 2022

1. Information:

- **PhD student:** Giancarlo D'Ago
- **DR number:** DR996238
- **Date of birth:** 13/09/1997
- **Master Science degree:** Automation Engineering - **University** of Naples 'Federico II'
- **Doctoral Cycle:** XXXVII
- **Scholarship type:** CERN Doctoral Student Programme
- **Tutor:** Prof. Fabio Ruggiero
- **Co-tutor:** Dr. Eng. Luca Rosario Buonocore, Prof. Vincenzo Lippiello

2. Study and training activities:

Activity	Type[1]	Hours	Credits	Dates	Organizer	Certificate[2]
Is control a solved problem for aerial robotics research?	Seminar	1	0.2	12/01/2023	DIETI	Y
10th BE-CEM Student's Coffee	Seminar	1	0.2	20/01/2023	CERN	Y
Astrononauts-in-the-loop mobile manipulation for planetary surface infrastructure mainteinance	Seminar	1	0.2	25/01/2023	CERN	Y
Multi-robot control of heterogeneous herds	Seminar	1	0.2	16/02/2023	DIETI	Y
Study on: (i) Theoretical background on partial feedback linearization, zero-dynamic nonlinear analysis (ii) Dynamic model in MATLAB of a cable-suspended dual arm articulated robot (iii) Simulation in C++, ROS, Gazebo of model-based control on simplified dual-arm cable suspended structures with implementation of trajectory tracking for passive joints. Preparation of the paper "Modelling and identification methods for simulation of cable-suspended dual-arm robotic systems". Laboratory activity: (i) Testing Aruco markers code detection for pose estimation (ii) Coding the control of lightweight manipulators, testing different reference	Research		9.2	From 01/01/2023 to 28/02/2023		

trajectories (iii) First implementation and testing of a model-free control on a dual-arm cable suspended robot. Evaluation of the performances.						
From Romeo & Juliet to OceanOneK Deep-Sea Robotic Exploration	Seminar	1	0.2	23/03/2023	DIETI	Y
ABP Alumni Forum	Seminar	4	0.8	27/03/2023	CERN	Y
Academic training lecture series "Open Source"	Seminar	5	1.0	27-31/03/2023	CERN	Y
How to Publish Under the CARE-CRUI Open Access Agreement with IEEE	Seminar	2	0.4	05/04/2023	UNINA IEEE	Y
Study on: (i) Rework on the generation of the dynamic model in MATLAB of a cable-suspended dual arm articulated robot (CERN's Cranebot); (ii) Preliminary identification of CERN's Cranebot dynamics. Preparation of the paper "Modelling and identification methods for simulation of cable-suspended dual-arm robotic systems". Revision of the T-RO Paper Li Guanrui, Xinyang Liu, Loianno Giuseppe - "RotorTM: A Flexible Simulator for Aerial Transportation and Manipulation". Laboratory activity: (i) Configuration of Ingenia Drivers for Harmonic Drives motors of the FCC Long Reach Manipulator (ii) Generation of the trajectories for the excitation of the oscillation dynamics of CERN's Cranebot robotic platform (iii) Coding control for simulataneous trajectory tracking for a dual arm system (iv) Measurements of Cranebot oscillations through PTZ and ArUco Markers pose estimation in two case of study: free oscillation and oscillation generated through the movement of the arms (v) Mounting motion capture system setup for	Research		7.6	From 01/03/2023 to 30/04/2023		

robots (manipulators and ground robots) pose estimation (vi) Testing parallel computing toolbox on CERN's clusters						
2023 Spring School on Transferable Skills	Course	/	2.0	24-25/05/2023	UNINA	Y
ATS Seminar on IPAC 2023 oral contributions	Seminar	2	0.4	25/05/2023	CERN	Y
BE-CEM Technical Meeting: ML on crystal alignment	Seminar	1	0.2	23/06/2023	CERN	Y
UPM Collaboration on Robotics	Seminar	3	0.6	26/06/2023	CERN	Y
Study on: (i) Identification of CERN's Cranebot dynamics in two cases of study: free oscillation and oscillation generated through the movement of the arms (ii) Sim-to-real comparison of Cranebot arms-induced oscillation. Preparation and Submission of the paper "Modelling and identification methods for simulation of cable-suspended dual-arm robotic systems" to Robotics and Automation Letters (RA-L). Laboratory activity: (i) Measurements of Cranebot oscillations through PTZ and ArUco Markers pose estimation (ii) Re-testing model free oscillation suppression control for parameters influence evaluation (iii) Setup motion capture system setup software (Vicon Tracker)	Research		6.8	From 01/05/2023 to 30/06/2023		
Learn To Be Stable: Imitation Learning With Dynamical Systems	Seminar	1.5	0.3	05/07/2023	CERN	Y
12th BE-CEM Student's Coffee	Seminar	1	0.2	05/07/2023	CERN	Y
ARCHE 2023: Advanced Robotic Capabilities for Hazardous Environments	Seminar	2	0.4	13/07/2023	CERN	Y
Study on: (i) Theory and stability consideration behind model-free control tested in laboratory: (a) Modelling of a double pendulum, energy definition of a double pendulum (b) Relationship configuration-potential energy (c) State of the art on energy-based	Research		9.1	From 01/07/2022 to 31/08/2022		

controls for the down-swing of an Acrobot (d) State-of-the art on energy-based up-swing of an Acrobot with collocated partial feedback linearization, study on its application for the down-swing; (ii) Simulation and testing of an Acrobot and its energy under energy-based controls. Laboratory activity: (i) Starting implementation of the Motion Capture class in the CRF (CERN Robotic Framework) (ii) Prepared and submitted CERN's CRANEBot Documentation						
Reconfigurable Robots for Real Intuitive Interactions	Seminar	1	0.2	06/09/2023	CERN	Y
Design and validation of a safe mechatronic system for the handling of radioactive sources	Seminar	1	0.2	06/09/2023	CERN	Y
Mixed Reality human-robot interface for remote operations in accelerator facilities	Seminars	1	0.2	27/10/2023	CERN	Y
Study on: (i) Theory and stability consideration behind model-free control tested in laboratory. Energy-based down-swing of an Acrobot with collocated partial feedback linearization. Study on zero-dynamics. (ii) Simulation and testing of an Acrobot and its energy under energy-based controls (iii)-Small angle approximation for double pendulum and normal modes of oscillation. Review Paper "RotorTM: A Flexible Simulator for Aerial Transportation and Manipulation" for Transaction on Robotics (T-RO). Preparation and Submission of the paper "Modelling and Identification Methods for Simulations of Dual-Arm Cable-Suspended Robotic Systems" to Robotics and Autonomous System. Laboratory activity:	Research		9.4	From 01/09/2023 to 31/10/2023		

(i) Implementation of Motion Capture class in the CRF (CERN Robotic Framework). First implementation of a Mock class and Development of Unit Testing. (ii) Testing and Fixing PTZ Cameras on CERN Robotic platform (iii) Preliminary mechanical analysis and market research for the integration of a Encoder for vertical rotational joint of CERN's CRANEBot. (iv) Installation of an IMU on CERN Robotic Platform. Performance analysis for pose estimation detection with comparison with Motion Capture ground truth. (v) First implementation in simulation of an MPC control for CERN robotic platform (vi) Real tests on University of Seville's long-reach aerial dual-arm robotic platform of noncollocated partial feedback linearization for oscillation suppression.						
Convincing Scientific Presentations	Course	20.0	2.0	06/11/2023 – 20-11-2023	CERN	Y
Review Paper "On the Collocated Form with Input Decoupling of Lagrangian Systems" for Transaction on Robotics (T-RO). Laboratory activity: (i) Full Implementation of Vicon APIs and Motion Capture modules in the CRF (CERN Robotic Framework). Unit testing and merge request. (ii) Implementation code of Gable IMU SE2 with EtherCAT communication for CRF (CERN Robotic Framework). (iii) Preliminar restructuring of the Oscillation Suppression module for (CERN Robotic Framework). Installation and linking of Acados libraries for MPC control (iv) Tests Model-Free control on planar case by	Research		2.9	From 01/11/2022 to 31/12/2022		

closing the loop with the IMU. First trials on combined 3D oscillations with first joint redirection. (v) First successful tests of MPC control for oscillation suppression for a planar case with robustness to change of height.						

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**	**0.8**	**9.2**	**0.0**	**10.0**
Bimonth 2	**0.0**	**2.4**	**7.6**	**0.0**	**10.0**
Bimonth 3	**2.0**	**1.2**	**6.8**	**0.0**	**10.0**
Bimonth 4	**0.0**	**0.9**	**9.1**	**0.0**	**10.0**
Bimonth 5	**0.0**	**0.6**	**9.4**	**0.0**	**10.0**
Bimonth 6	**2.0**	**0.0**	**2.9**	**0.0**	**4.9**
Total	**4.0**	**5.9**	**45.0**	**0.0**	**54.9**
Expected	**30 - 70**	**10 - 30**	**80 - 140**	**0 - 4.8**	

3. Research activity:

Long-reach robotic manipulation aims to perform inspection and maintenance tasks in difficult-to-access workspaces. A recent challenge in this field is the execution of operations in high-altitude areas (e.g., maintenance of power lines, inspection of infrastructures, etc.) where the direct access of humans is dangerous or costly. It is clear that, in this context, the use of conventional serial or parallel robots is impractical due to their limited workspace, and alternative robot designs must be leveraged. In these scenarios, manipulators in a long-reach pendulum configuration are usually employed. They are constructed using one or multiple cables that: (i) dramatically decrease the weight of the overall robotic system compared to using rigid links only; (ii) provide orders of magnitude larger end-effector workspace without affecting the weight of the manipulators' base; and (iii) exhibit superior resilience to absorb external disturbances such as impacts and collisions. Despite the clear advantages of using cable-suspended long-reach manipulators, they are generally more difficult to control due to the presence of non-actuated and flexible elements (cables) that make the entire system prone to uncontrolled oscillation.

The conducted research aims to model, identify, simulate, and control this type of systems. The study carried out during this second year involved the improvement and refinement of the kinematics and dynamic models developed during the first year with the aim of better capturing the dynamic effect of a suspended articulated system.

For the study of the dynamics, the behaviour of two case studies has been analysed: the first system is a bi-manual system designed by the BE-CEM-MRO section at the European Organization for Nuclear Research (CERN) for the inspection and maintenance of particle accelerator-related infrastructures. In this case, a set of pulleys and steel ropes, coupled through a hook to a lower platform, serves as a lifting mechanism to hoist an articulated system (two Pilz PRBT6 arms) from an overhead crane. The second is an aerial cable-suspended dual-arm system developed by the GRVC Robotics Labs at the University of Seville used to install bird diverters on high-voltage power line. In that system, four belts, tied in a parallel pattern to a drone and to a lower platform, hold two four-DoF (Degree of Freedom) manipulators.

Long-reach cable-suspended articulated system modelling was carried out using the screw theory and Newton-Euler approaches. Since the real cable structure forms a closed kinematic chain, an equivalent open kinematic chain is adopted to simulate these systems using customary rigid-body dynamic simulators. The equivalence between the adopted open kinematic chain and the real system has been established by finding a set of dynamic parameters that maximize the similarity of their dynamic response. A set of experiments was conducted on both the systems case of study, and an identification procedure involving the solution of an optimization problem was developed. The experiments of the second year involved also the movement of the arms, so to capture the coupling dynamic effect between the robotic arms and the suspension mechanism. Once an estimate has been obtained, parameters are appropriately replaced into the model, and the behaviour of the simulated system is compared with a new set of experiments on the real platforms. During the second year a more realistic simulation setup has been developed. This has brought to a faster development of control strategies, as well as a safe testing environment. This research work led to the production of a conference paper [P2] submitted in September 2023 to Elsevier Robotics and Autonomous Systems (RAS) Journal, which is the result of a collaboration between CERN, PRISMA Lab of University of Naples 'Federico II' and GRVC Robotics Lab of University of Seville.

The control problem addressed during the second year is the suppression of the oscillation of the system during the transportation of the dual-arm robotic system. As anticipated, despite the advantages of using cable-suspension, the system is prone to difficult-to-control oscillations, hence the objective of the control is to reduce the settling time of the oscillation. This first phase of the research addresses the actuation of the articulated system only to accomplish the suppression task. Three different control strategies have been studied. The first is a model-based control strategy, namely non-collocated partial feedback linearization, suitable for underactuated system. While during the first-year simulations through mathematics computation softwares (MATLAB), rigid-body dynamic simulators (Gazebo) and Operating Systems for Robotics (ROS) were carried out, the second year has led to real tests of this control strategies on the aerial platform of the University of Seville. This research work is suitable to be submitted to a conference at the beginning of the third year. The second is a model-free energy-based control technique, which has been implemented and tested both at University of Seville and at CERN. The third strategy is a Model Predictive control approach, which is currently under testing for the CERN platform. It is envisaged that these works will lead to the production and submission of one or more scientific articles to internationally renowned journals.

During the coming year, the theoretical foundations of the controls will be further investigated for performance evaluation and a full implementation and testing in a real case scenario is foreseen. The control laws will be tested in different application cases and in real operation scenarios.

4. Research products:

[P1]
Scientific paper: Modelling and control of a variable-length flexible beam on inspection ground robot
Authors: G. D'Ago, M. Lefebvre, L. R. Buonocore, F. Ruggiero, M. Di Castro, V. Lippiello
Conference: IEEE International Conference on Robotics and Automation (ICRA), 2022
Year of publication: 2022
Current state: published.

[P2]
Scientific paper: Modelling and identification methods for simulation of cable-suspended dual-arm robotic systems
Authors: G. D'Ago, M. Selvaggio, A. Suarez, F. J. Ganán Onieva, L. R. Buonocore, V. Lippiello, A. Ollero, F. Ruggiero
Conference: IEEE International Conference on Robotics and Automation (ICRA), 2023
Current state: submitted.

5. Conferences and seminars attended

6. Periods abroad and/or in international research institutions

7. Tutorship

8. Plan for year three

The research of the third year will cover the oscillation suppression during transportation of dual-arm robotic systems. It's foreseen a full implementation and integration of the control for real case scenarios. The second part of the third year could cover the problem of reactionless manipulation for the enhancing of the efficiency of the teleoperation for cable-suspended dual-arm systems. A draft title of the thesis is "Dynamic compensation algorithms for manipulation and transportation of non-rigid robotic platforms".