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

PhD Student: Francesco Cufino

Cycle: XXXIX

Training and Research Activities Report

Academic year: 2023-24 - PhD Year: First

Francesco Cufino

Tutor: prof. Fabio Ruggiero

Fabio Ruggiero

Date: November 04, 2024

1. Information:

- **PhD student: Francesco Cufino** **PhD Cycle: XXXIV**
- **DR number: DR997190**
- **Date of birth: 20/03/1999**
- **Master Science degree: Automation and Robotics Engineering**
  University: Università degli studi di Napoli Federico II
- **Scholarship type: PNRR - DM 118/2023**
- **Tutor: Fabio Ruggiero**

2. Study and training activities:

Activity	Type[1]	Hours	Credits	Dates	Organizer	Certificate[2]
Numerical Optimization	Course	20	4	20/11/2023 – 15/12/2023	IMT Lucca, Prof. Alberto Bemporad	Y
Multi-agent autonomous flight at Leonardo Labs	Seminar	1	0.2	21/12/2023	Prof. Vincenzo Lippiello	Y
-Study of state of the art on: non-prehensile pushing; whole-body control -Development of a theory for compliant non-prehensile pushing and preparation of the related paper -Integration at ABB Research Center, Västerås, Sweden -Contribution for revision of a paper for IEEE Transaction on Robotics (T-RO)	Research		5.8	01/11/2023 – 31/12/2023		

-Laboratory activity: experiments for compliant non-prehensile pushing at PRISMA LAB and at ABB Research Center, Västerås, Sweden						
Neural Networks and Deep Learning: Theoretical Foundations	**Course**	**30**	**3**	**09/01/2024 – 21/02/2024**	**Scuola Superiore Sant'Anna di Pisa, Prof. Giorgio Buttazzo**	**Y**
Lessons Learned from Superhuman Autonomous Drone Racing	**Seminar**	**1**	**0.2**	**10/01/2024**	**Prof. Bruno Siciliano**	**Y**
-Study of state of the art on: passivity-based control -Extension of the theory for compliant non-prehensile pushing to passive non-prehensile pushing and preparation of the related paper -Simulation of non-prehensile passive pushing -Contribution for revision of a paper for Robotics and Autonomous Systems (RAS) -Laboratory	**Research**		**6.8**	**1/01/2024 – 29/02/2024**		

activity: experiments for passive non-prehensile pushing at ABB Research Center, Västerås, Sweden						
Analytic center selection of optimization-based controllers for robot ecology	**Seminar**	**1**	**0.2**	**09/04/2024**	**Prof. Bruno Siciliano**	**Y**
-Further development of the theory for compliant non-prehensile passive pushing and preparation of the related paper -Simulation of compliant non-prehensile passive pushing -Submitted two reviews for International Conference on Intelligent Robots and systems (IROS)	**Research**		**9**	**01/03/2024 – 30/04/2024**		
"Teoria dei sistemi" (Dynamic systems theory): -Introduction to MATLAB -Exercises on diagonalization, Jordanization, power matrix, exponential matrix, stability with MATLAB	**Tutorship**	**4**	**0.8**	**01/03/2024 – 30/04/2024**	**Prof. Fabio Ruggiero**	
Innovation and Entrepreneurshi	**Course**	**12**	**4**	**12/14/21 – 26/06/2024**	**Prof. Pierluigi**	**Y**

p					**Rippa**	
Optimization-Based Planning and Control for Multi-Limbed Walking Robots	**Seminar**	**1**	**0.2**	**27/05/2024**	**Prof. Bruno Siciliano**	**Y**
Simultaneous Perception and Manipulation	**Seminar**	**1**	**0.2**	**21/06/2024**	**Prof. Bruno Siciliano**	**Y**
-Further implementation of compliant non-prehensile passive pushing simulation and preparation of the related paper -Laboratory activity: experiments for object pose estimation on a tray through vision and force at PRISMA LAB	**Research**		**3.2**	**01/05/2024 – 30/06/2024**		
"Teoria dei sistemi" (Dynamic systems theory): -Block diagram algebra -High-pass filter, Bode diagrams exercise -Z-transform for discrete time LTI systems -Transfer function and step response for discrete time systems -Finite Impulsive Response (FIR) systems; Sampled data systems: sampler and holder	**Tutorship**	**12**	**2.4**	**01/05/2024 – 30/06/2024**	**Prof. Fabio Ruggiero**	

-Sampled data systems: state-space representation, transfer function representation, eigenvalues mapping						
SIDRA 2024 PhD Summer school: -Introduction to the Analysis and Control of Nonlinear Systems (lecturer: Prof. Lorenzo Marconi) -Data-driven control design (lecturers: Prof. Claudio De Persis, Prof. Pietro Tesi)	**Course**	**30**	**6**	**08/07/2024 – 13/07/2024**	**Prof. Claudio Melchiorri and Prof. Maria Elena Valcher**	**Y**
-Paper Compliant Non-prehensile Pushing Manipulation completed and ready to be submitted	**Research**		**4**	**01/07/2024 – 31/08/2024**		
-Paper Compliant Non-Prehensile Pushing Manipulation internally revised and submitted -Study of the state of the art of wheelchair pushing through mobile manipulator -Tested in	**Research**		**10**	**01/09/2024 – 31/10/2024**		

simulation direct and indirect adaptive control for wheelchair pushing -Contribution for review of a paper for Robotics and Automation Letters (RAL)						

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	**4**	**0.2**	**5.8**	**0**	**10**
Bimonth 2	**3**	**0.2**	**6.8**	**0**	**10**
Bimonth 3	**0**	**0.2**	**9**	**0.8**	**10**
Bimonth 4	**4**	**0.4**	**3.2**	**2.4**	**10**
Bimonth 5	**6**	**0**	**4**	**0**	**10**
Bimonth 6	**0**	**0**	**10**	**0**	**10**
Total	**17**	**1**	**38.8**	**3.2**	**60**
Expected	**30 - 70**	**10 - 30**	**80 - 140**	**0 – 4.8**	

3. Research activity:

Topic

The research activity carried out in the current year is about non-prehensile manipulation applied in service robotics for healthcare.

Service robotics for healthcare has the goal to assist either healthcare personnel or patients executing tasks like transporting sanitary material. Integrating robots in non-structured human-centered environment like hospital requires enabling two fundamental skills: human-like dexterous manipulation abilities and compliant, and potentially safe, physical human-robot interaction.

For what concerns the manipulation, it is widely recognized that the most advanced and versatile manipulative actions are performed using non-prehensile techniques, useful for manipulating items that are too large or must be brought outside the robot's workspace. Non-prehensile manipulation circumvents the difficult problem of grasping an object and jointly exploits frictional, gravity, and inertial forces. The focus of this work is on pushing manipulation. Several non-prehensile pushing techniques have been proposed in the past, although the possibility of deploying these in a human-populated environment remained largely unexplored. This requires a safe human-robot interaction, so it

has been investigated how to execute non-prehensile pushing manipulation task with a robot able to exhibit a compliant and passive behaviour while performing its task.

The considered illustrative case-study consists in a robot delivering by pushing a rack containing test tubes to a human operator to speed up their processing operation.

Methodology
The methodology developed is based on an extension of the non-prehensile pushing framework based on model predictive control (MPC) and complementarity constraints to allow using an impedance-controlled robot to execute a non-prehensile pushing task, while guaranteeing the passivity of the system. In the framework, the model with complementarity constraints is extended to command the impedance-controlled robot in such way it can realize at the same time a certain pushing force on the object while changing also the contact point sliding on the object edge if needed.

This MPC generates an optimal position/velocity set-point provided to the impedance-controlled robot which jointly realizes the force on the object, changes the contact point and exhibits spring-damper behaviour with respect to the external interactions. However, external interactions (possibly caused by a human) may prevent the manipulator from pushing the object along the desired trajectory, causing an increase of the tracking error. The consequence is that the MPC controller reacts to this generating an increase of the pushing force to compensate for it. This is a clearly undesired and a potentially harmful behaviour that can be physically interpreted as a (potentially unlimited) increase of the interacting system internal energy. To prevent this, in the control framework a virtual energy tank is included, which allows using the energy of the controlled system in a passivity preserving way. With the energy-tank filter, a passive version of the optimal velocity set-point is thus generated. As a result, when the passivity bound tends to be violated, the robot stops increasing the pushing force, keeping the energetic level constant, thus preserving the safety of the overall interacting system.

Results
The results of the developed framework have been obtained both in simulation and in real world experiments. The scenario consists of a robot manipulator equipped with a spherical/cylindrical-shaped end-effector and with an eye-in-hand camera, which pushes a box-shaped object along a desired trajectory. During the execution of the task, an external interaction due to a human operator occurs, hindering the motion. It has been shown that, in this circumstance, the compliant and passive behaviour is exhibited: the robot avoids increasing the pushing force when passivity is going to be violated, stopping the task execution, and resuming it when the motion is not hindered anymore.

4. Research products:

Scientific paper: **Compliant Non-Prehensile Pushing Manipulation.**
Authors: **Francesco Cufino, Mario Selvaggio, Fabio Amadio, Fabio Ruggiero.**
Journal: **IEEE Transactions on Robotics.**
Current state: **submitted.**

5. Conferences and seminars attended

6. Activity abroad

Integration of Compliant Non-Prehensile Pushing framework at ABB Research Center, Västerås, Sweden, from 3/12/2023 to 19/12/2023.

7. Tutorship

"Teoria dei sistemi" (Dynamic systems theory), 16 hours:

- Introduction to MATLAB.
- Exercises on diagonalization, Jordanization, power matrix, exponential matrix, stability with MATLAB.
- Block diagram algebra.
- High-pass filter, Bode diagrams exercise.
- Z-transform for discrete time LTI systems.
- Transfer function and step response for discrete time systems.
- Finite Impulsive Response (FIR) systems; Sampled data systems: sampler and holder.
- Sampled data systems: state-space representation, transfer function representation, eigenvalues mapping.