
**PhD in Information Technology and Electrical Engineering**

**Università degli Studi di Napoli Federico II**

# PhD Student: Pierluigi Arpenti

**XXXIII Cycle**

**Training and Research Activities Report –Third Year**

**Tutor: Vincenzo Lippiello–co-Tutor: Fabio Ruggiero**

# 1. Information

I am Pierluigi Arpenti, Ms.C. in Automation Engineering – Università degli Studi di Napoli Federico II, Department of Information Technologies and Electrical Engineering – September 2016. Master thesis title: "A High Level Control Architecture for Simultaneous Localization, 3D Mapping and Navigation for Mobile Robots", developed at Prisma Lab of Università degli Studi di Napoli Federico II. Currently PhD student in Information Technology and Electrical Engineering, XXXIII Cycle, at Università degli Studi di Napoli Federico II with a MIUR fellowship, supervised by Prof. Vincenzo Lippiello and Prof. Fabio Ruggiero.

# 2. Study and Training activities

## Courses

| Lecture/Activity | Type | Credits | Certification | Notes |
|---|---|---|---|---|
| Robot Interaction Control | M. Sc. module | 6 | x | |
| Field and Service Robotics | M. Sc. module | 6 | x | |
| Robotics Lab | M. Sc. module | 6 | x | |

## Seminars

| Lecture/Activity | Type | Credits | Certification | Notes |
|---|---|---|---|---|
| Introduction to Underwater Robotics | Seminars | 0,4 | x | |

# 3. Research activity

During this third Ph. D. year, my research activity focused on the passivity-based control of bipedal robots. After a first period spent studying the state-of-the-art locomotion control of biped robots, I have faced the gait robustification problem, as well as, the gait stabilization one, taking into account the hybrid nature of walking. The former is the enlargement of the basin of attraction of the limit cycle representing the periodic walking exhibited by the biped. The latter is the stabilization to the desired limit cycle via gain adjustment. Gait robustification has been solved using a strategy based on Energy Pumping-and-Damping Passivity-Based Control (EPD-PBC) which exponentially stabilizes the system to a target energy value, with the beneficial effect to enlarge the basin of attraction of the limit cycle. The objective of this research is to provide a methodology to extend the range of possible initial conditions leading to periodic walking. The proposed approach exploits the passivity of the system, the invariant sets theory, and the Hybrid Zero Dynamics (HZD) concept, rather than Poincaré maps, to study the stability of the periodic solutions. Besides, the stability is demonstrated exploiting the absence of non-conservative forces during continuous (swing) dynamics, that is the system is conservative during swing phases and dissipation takes place only at impacts. Moreover, this condition is instrumental to the application of the approach. Hence, EPD-PBC can be indiscriminately applied to both the passive system and the system controlled via energy shaping, provided that the latter preserves the principle of energy conservation characterizing the passive one. An Interconnection and Damping Assignment Passivity-Based Control (IDA-PBC) approach has been exploited to generate new gaits. IDA-PBC applied to swing dynamics guarantees that the system remains conservative. Hence an outer EPD-PBC control law has been applied to increase the robustness of the generated gaits. Concerning gait stabilization, an approach to solving such a problem for hybrid systems is currently under development. The methodology investigated is based on the Mexican-Sombrero

Energy Assignment Passivity-Based Control (MSEA-PBC), which is a control strategy aimed at imposing a target Mexican sombrero-like energy function to induce the system to exhibit a stable limit cycle. Such a strategy has to be merged with HZD, as done in the case of EPD-PBC for gait robustification. Only in this way, by incorporating the HZD concept, gait design can be realized through gain adjustment.

# 4. Products

## Published Papers

P. Arpenti *et al.*, "Interconnection and Damping Assignment Passivity-Based Control for Gait Generation in Underactuated Compass-Like Robots," *2020 IEEE International Conference on Robotics and Automation (ICRA)*, 2020, pp. 9802-9808,doi: 10.1109/ICRA40945.2020.9196598.

M. Nacusse *et al*., "Gait Generation for Underactuated Compass-Like Robots Using Dissipative Forces in the Controller," IFAC-Papers Online, vol. 53, no. 2, pp. 9023-9030, 2020. 21th IFAC World Congress, https://doi.org/10.1016/j.ifacol.2020.12.2022.

P. Arpenti *et al*., "RGB-D Recognition and Localization of Cases for Robotic Depalletizing in Supermarkets," in *IEEE Robotics and Automation Letters*, vol. 5, no. 4, pp. 6233-6238, Oct. 2020, doi: 10.1109/LRA.2020.3013936.

G. A. Fontanelli *et al*., "A Reconfigurable Gripper for Robotic Autonomous Depalletizing in Supermarket Logistics," in *IEEE Robotics and Automation Letters*, vol. 5, no. 3, pp. 4612-4617, July 2020, doi: 10.1109/LRA.2020.3003283.

R. Caccavale *et al*., "A Flexible Robotic Depalletizing System for Supermarket Logistics," in *IEEE Robotics and Automation Letters*, vol. 5, no. 3, pp. 4471-4476, July 2020, doi: 10.1109/LRA.2020.3000427.

## Accepted Papers

P. Arpenti *et al*., "Energy pumping-and-damping for gait robustification in underactuated planar biped robots within the hybrid zero dynamics framework,"2021 (in press).

P. Arpenti *et al*., "A Constructive Methodology for the IDA-PBC of Underactuated 2-DoF Mechanical Systems with Explicit Solution of PDEs,"2022 (in press).

# 5. Conferences

IEEE International Conference on Robotics and Automation (ICRA) 2020, Virtual Conference, 31/05/2020-31/08/2020

IFAC World Congress 2020, Virtual Conference, 11-17/07/2020

IEEE International Conference on Intelligent Robots and Systems (IROS) 2020, Virtual Conference, 25/10/2020-24/01/2021

# 6. Tutorship

Didactic assistance to Professor Bruno Siciliano relatively to the Ms.C. course “Robotics Foundations”. Co-tutor of one BSc and one MSc thesis.

# 7. Summary of Credits

| | Credits year 1 | | | | | | | | Credits year 2 | | | | | | | | Credits year 3 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | | | 1 | 2 | 3 | 4 | 5 | 6 | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | | | |
| | Estimated | bimonth | bimonth | bimonth | bimonth | bimonth | bimonth | Summary | Estimated | bimonth | bimonth | bimonth | bimonth | bimonth | bimonth | Summary | Estimated | bimonth | bimonth | bimonth | bimonth | bimonth | bimonth | bimonth | bimonth | month | Summary | Total | Check |
| **Modules** | 18 | 0 | 4 | 9 | 5 | 0 | 0 | 18 | 8 | 1,2 | 0 | 4,2 | 0 | 0 | 0 | 5,4 | 7 | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 6 | 18 | 41 | 30-70 |
| **Seminars** | 13 | 1,4 | 1 | 1 | 3 | 0 | 0,2 | 6,6 | 4 | 0,2 | 0,2 | 0,6 | 3 | 0,2 | 0 | 4,2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,4 | 0,4 | 11 | 10-30 |
| **Research** | 34 | 6 | 6 | 3 | 3 | 9 | 9 | 36 | 47 | 6 | 8 | 8 | 8 | 8 | 8 | 46 | 48 | 8 | 8 | 6 | 8 | 8 | 8 | 8 | 8 | 3 | 65 | 147 | 80-140 |
| | 65 | 7,4 | 11 | 13 | 11 | 9 | 9,2 | 61 | 59 | 7,4 | 8,2 | 13 | 11 | 8,2 | 8 | 56 | 55 | 8 | 8 | 18 | 8 | 8 | 8 | 8 | 8 | 9,4 | 83 | 200 | 180 |

| Year | Lecture/Activity | Type | Credits | Certification | Notes |
|---|---|---|---|---|---|
| | **MODULES** | | | | |
| 1 | Delay differential equations (DDEs) and their applications | Ad hoc module | 3 | x | |
| 1 | Introduction to modeling and control of mechanical systems with constraints | Ad hoc module | 2 | x | |
| 1 | Image processing for computer vision | MS module | 9 | x | |
| 1 | Geometric theory of soft robotics | External module | 4 | x | |
| 2 | Data Science and Optimization | Ad hoc module | 1,2 | x | |
| 2 | Machine Learning | Ad hoc module | 4,2 | x | |
| 3 | Robot Interaction Control | MS module | 6 | x | |
| 3 | Field and Service Robotics | MS module | 6 | x | |
| 3 | Robotics Lab | MS module | 6 | x | |
| | **SEMINARS** | | | | |
| 1 | Dynamic control: mathematical challenges and applications | Seminar | 0,4 | x | |
| 1 | Etica e intelligenze artificiali | Seminar | 0,5 | x | |
| 1 | Le nuove frontiere della robotica cognitiva e l’interazione uomo-robot | Seminar | 0,5 | x | |
| 1 | Razionalità limitata nell’uomo e nella macchina | Seminar | 0,6 | x | |
| 1 | The age of human-robot collaboration | Seminar | 0,4 | x | |
| 1 | IBM:Q: building the first universal quantum computers for business and science | Seminar | 0,8 | x | |
| 1 | How does mathworks accelerate the pace of engineering and science | Seminar | 0,2 | x | |
| 1 | Domains of attraction and manifolds in a gear model | Seminar | 0,2 | x | |
| 1 | Adaptive control systems: methodologies for analysis and synthesis | Doctoral School | 1,5 | x | |
| 1 | Optimization methods for decision making over networks | Doctoral School | 1,5 | x | |
| 2 | Issues in Robotic Manipulation of Deformable Objects | Seminar | 0,2 | x | |
| 2 | Spin-Orbit Optical Phenomena | Seminar | 0,2 | x | |
| 2 | Presentazione ADI: vittorie, sfide, obiettivi | Seminar | 0,2 | x | |
| 2 | Control of Multi-Robot systems: from rendez-vous to long-duration autonomy | Seminar | 0,2 | x | |
| 2 | PID Passivity-Based Control: Application To Energy and Mechanical Systems | Seminar | 0,2 | x | |
| 2 | Innovation in Medical Robotics and the Human Centered Paradigm | Seminar | 0,2 | x | |
| 2 | Model Reduction by Moment Matching for Linear and Nonlinear Systems | Doctoral School | 1,5 | x | |
| 2 | Intelligent Collaborative Robotics | Doctoral School | 1,5 | x | |
| 3 | Introduction to Underwater Robotics | Seminar | 0,4 | x | |