PhD in Information Technology and Electrical Engineering

Università degli Studi di Napoli Federico II

PhD Student: Diana Serra

XXIX Cycle

Training and Research Activities Report – Third Year

Tutor: Prof. Vincenzo Lippiello – co-Tutor: Dr. Ing. Fabio Ruggiero

1. Information

Diana Serra has a Master Degree in Automation Engineering, from Università di Napoli Federico II. She is currently a PhD candidate in Information Technology and Electrical Engineering (ITEE), XXIX Cycle, at Università di Napoli Federico II, under the supervision of Prof. Vincenzo Lippiello (tutor) and Dr. Ing. Fabio Ruggiero (co-tutor). Her fellowship is named *Controllo di Robot per la Manipolazione Dinamica*, and is funded by Consorzio di Ricerca per l'Energia e le Applicazioni dell'Elettromagnetismo (CREATE).

2. Study and Training Activities

Year	Lecture/Activity	Type	Credits	Certification
1	Discrete Events Systems	MS module	6	x
1	Meccanica quantistica	Ad Hoc Module	3	x
1	Theory and Applications of Piecewise Smooth Dynamical Systems	Ad Hoc Module	5	x
1	Introduction to the Analysis and Control of Nonlinear Systems, Unmanned Aerial Vehicles	Doctoral School	4	x
1	Europrogettazione	Ad Hoc Module	3	x
1	Quantum Circuit	Seminar	0,2	x
1	Insisting on an Anonymous (leaderless) Approach to Collective Robotics	Seminar	0,4	x
1	Plasmon Resonances and Riemann Hypothesis	Seminar	0,4	x
1	High-Dimensional Pattern Recognition via Sparse Representation	Seminar	0,4	x
1	Jtilizzo di Reti di Petri per la diagnosi dei guasti e per la modellistica ed il controllo dei sistemi logistic	Seminar	0,6	x
1	Towards agile flight of vision-controlled micro flying robots: from frame-based to event-based vision	Seminar	0,2	x
1	Fractional Programming for Energy Efficiency in Wireless Networks	Seminar	0,6	x
1	Ciclo di seminari su Nano-carbon based components and materials for high frequency electronics	Seminar	0,8	x
1	Developmental Robotics: From Babies to Robots	Seminar	0,4	x
1	Quantum Teleportation	Seminar	0,2	x
1	Heterogeneities in temporal networks emerging from adaptive social interactions	Seminar	0,2	x
1	Methods and tools for smart device integration and simulation	Seminar	0,4	x
1	oothed particle machine perception: a proposed method for sensor fusion and physical-spacial percep	Seminar	0,2	x
1	Mechanics of solids: from beam theory to rapid propotyping for surgery planning	Seminar	0,2	x
2	English course	Ad Hoc Module	6	x
2	ng and writing scientific manuscripts for publication in English language scholarly journals, and relatec	Ad Hoc Module	3	x
2	MPC for plasma magnetic control	Seminar	0,6	x
2	Observability of switched systems	Seminar	0,3	x
2	Controllability of switched systems	Seminar	0,3	x
2	Colloquium on Robotics Six Keynote Talks by International Experts	Seminar	1	x
2	On Abel Differential Equations of the 2nd Kind and Exact Inversion of Boost DC/AC converters	Seminar	0,2	x
2	Passivity-based control of nonlinear physical systems: A port-Hamiltonian approach	Seminar	2	x
2	On Motion Planning, Motion Representation and its Orbital Stabilization for Mechanical System	Seminar	0,2	x
2	Real-Time Embedded Control Systems	Seminar	1,2	x
2	Test and Diagnosis of Integrated Circuits	Seminar	2,4	x
2	Hardware Security and Trust	Seminar	2,4	x
2	Armi autonome: problemi etici e decisioni politiche	Seminar	0,4	x
2	Robot Control	Doctoral School	1,8	x

Student: Diana Serra	Tutor: Vincenzo Lippiello	Co-Tutor: Fabio Ruggiero	Cycle XXIX
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	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			
	Estimated	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	Summary	Estimated	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	Summary	Estimated	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	Summary	Total	Check
Modules	18	0	11	7	3	0	0	21	9	0	9	0	0	0	0	9	0	0	0	0	0	0	0	0	30	30-70
Seminars	13	0,2	1,8	0	2,2	0,6	0,4	5,2	6	2,2	2,2	1,8	0	6,8	0	13	0	0	0	0	0	0	0	0	18	10-30
Research	34	9	1	4	3	9	7,8	34	42	7	1	8	11	9	10	46	52	8	8	8	8	10	10	52	132	80-140
	65	9,2	14	11	8,2	9,6	8,2	60	57	9,2	12	9,8	11	16	10	68	52	8	8	8	8	10	10	52	180	180

3. Research Activity: Motion Planning and Control Methods for Nonprehensile Manipulation and Multi-Contact Bipedal Locomotion

The robotic manipulation aims at finding a set of suitable controls to change the state of an object from an initial to a desired configuration. A manipulation task/action is said to be *nonprehensile* when the object is not directly caged between the fingertips or the palm of the hand. The force closure constraint does not hold during a nonprehensile manipulation action, and the grasp is then performed exploiting only unilateral constraints, allowing the object to roll, slide, and break the contacts with the manipulator [R1]. Examples of nonprehensile manipulations are in everyday life such as pushing objects, folding clothes, bringing wineglass on a tray, cooking in a pan, and many others. Nonprehensile manipulation is classified as *dynamic* when the dynamics of both the object and the robot are essential to successfully accomplish the task.

The analysis of objects with multiple frictional contacts poses two interesting problems. The forward problem, predicts the motion of an object given the applied force. Solving this is essential for simulation aspects. The inverse problem, predicts the applied forces producing a desired object motion, or the set of applied forces producing a desired contact mode. Solving this is essential for planning and control aspects. The research activity is mainly devoted to the inverse problem.

In the last decades, with the increase of powerful technology in both sensing and actuation speed, it has become possible the use of robots to manipulate an object in a very fast way. Indeed, the robotic community began to deal with nonprehensile dynamic manipulation tasks. Planning and control methods for such kind of tasks were firstly introduced in [R2] and [R3]. Nowadays, this class of manipulation problems is still rather far from being fully solved and applied in robotic applications. In such kind of manipulation, a kinematic chain cannot be always closed, with the drawback of not having a direct kinematics available. Moreover, when one of more contacts change their status, the dynamics of the system changes in a non-smooth manner making the design of the controller more involved. Since the object can perform a large variety of motions, most of nonprehensile systems are underactuated, arising controllability issues.

Nevertheless, without adding complexity to the mechanical design, nonprehensile dynamic manipulation offers several advantages: increase of available robot actions; enlargement of the operative workspace; reduction of task execution time; improvement of the dexterity in dynamic tasks. Applications of nonprehensile dynamic manipulation through robots span industrial, surgical, humanoid and service robotics. Examples of nonprehensile dynamic manipulations can be found in the control of vibratory platforms, usually employed in those applications where it is not directly possible to manipulate small or damageable objects which cannot be grasped. The problems of pushing, orienting and assembling parts have been extensively investigated for factory automation, where commercial bowl feeders, or parts orienting systems, are employed. Also in surgical robotics, some nonprehensile manipulations are performed, such as pushing away arteries and reshaping muscles or organs. In service robotics, the development of humanoid robots assisting elderly people in everyday tasks can be sped up with the extension of the set of available robot movements.

As it is possible to figure out so far, a nonprehensile manipulation action is a complex, skillful and dexterous task. It can be usually undertaken by splitting in simpler subtasks, usually called primitives, such as rolling, pushing, throwing, batting, dynamic catching, and so on. A supervisory control is then required to detect, identify and switch between the available primitives to perform the original complex dynamic nonprehensile manipulation task. The pursued methodology is then to study step by step each nonprehensile manipulation primitive, equipping this last with the proper motion planner and controller. The primitives considered in this work in are related to:

- Rolling tasks, involving a rolling constraint for balancing;
- Impact tasks, which exhibit a hybrid dynamics due to intermittent contacts between the object and the robot.

In this research, *passivity-based control* approaches are considered for the class of nonprehensile planar rolling. Besides the classical Euler-Lagrange modeling approach to robotic systems, also the Port-Hamiltonian systems formalism has been used for such tasks. Both Euler-Lagrange and Port-Hamiltonian formalism are energy-based representations exposing in complementary manners different physical properties of the systems related to the ways of energy processing, power flow and interconnection structure. This allows to exploit them for the design of control algorithms for tasks with non-negligible dynamics. Passivity-based control is chosen with the aim to exploit its potentiality to stabilize the system with the contribution of gravitational force, or centrifugal forces, avoiding the cancellation of the nonlinear dynamics of the system, that for dynamic manipulation tasks might play a relevant role. Exploiting the emerging development of fast solvers of linear and nonlinear problems, and relying on the technological advancement of the measurement systems, *optimal motion planning* techniques are instead proposed to deal with impact manipulations [P1, P4, P5].

Moreover, several analogies exist between the dynamic nonprehensile manipulation and walking tasks within locomotion applications. The walking task shares some hybrid contact/non-contact conditions with the manipulation task. In fact, methods for grasp analysis deal with the same constraints on contact forces and center of mass position that arise for legged robots on irregular and steep terrain, since during manipulation the surface of the object is rarely flat and horizontal [R4]. In the same way as grasp taxonomies are used to understand how the hand can hold an object, also taxonomies of the whole body pose for balancing are proposed in [R5], as tools for autonomous decision making. This classification of multi-contact whole body poses highlights that almost all the so-called *whole-body grasps* are nonprehensile [R6]. Such manipulation intrinsically involves multiple contacts and interaction between complex shapes, and then it can be related to legged locomotion in *multi-contact* situations. For this reason, the generation of motion for walking on uneven terrain in a multi-contact situation is inspected during the third year of the PhD course [P2]. A state constrained optimal control is designed with the aim to identify the set of possible - dynamically feasible - movements for a bipedal walking robot in a set of multi-contact configurations. A reference motion in case of interaction of a humanoid robot with external supports while walking on stairs (see Figure 1) is generated with *model predictive control*, extending the work [R7]. Nonlinear transformations of the system dynamics are designed with the aim to keep the computational burden compatible with the real-time [P3].

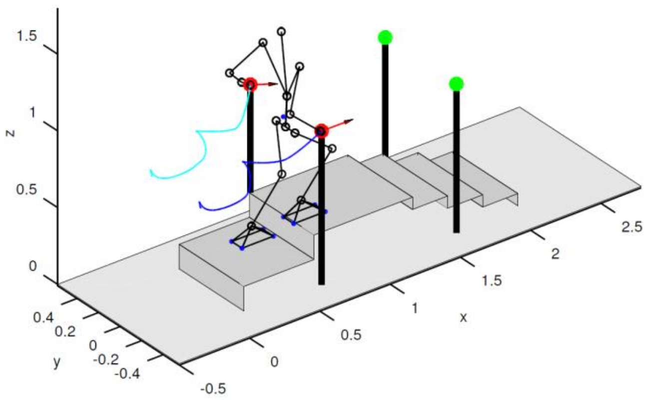

Figure 1: Simulation of the HRP-4 humanoid robot walking up stairs with hands support.

References

R1. R. M. Murray, Z. Li, and S. S. Sastry, *A mathematical introduction to robotic manipulation*, CRC press, 1994.
R2. K.M. Lynch and M.T. Mason, *Dynamic underactuated nonprehensile manipulation*, IEEE/RSJ International Conference on Intelligent Robots and Systems (Osaka, J), 1996, pp. 889-896.
R3. M.T. Mason and K.M. Lynch, *Dynamic manipulation*, IEEE/RSJ International Conference on Intelligent Robots and Systems (Tokyo, J), 1993, pp. 152-159.
R4. M.A. Ott, C.and Roa and G. Hirzinger, *Posture and balance control for biped robots based on contact force optimization*, IEEE-RAS International Conference on Humanoid Robots (Bled, SI), 2011, pp. 26-33.
R5. J. Borras and T. Asfour, *A whole-body pose taxonomy for loco-manipulation tasks*, IEEE/RSJ International Conference on Intelligent Robots and Systems (Hamburg, DE), 2015, pp. 1578-1585.
R6. T. Asfour, J. Borras, C. Mandery, P. Kaiser, E.E. Aksoy, and M. Grotz, *On the dualities between grasping and whole-body loco-manipulation tasks*, International Symposium on Robotics Research (Genova, I), 2015.
R7. C. Brasseur, A. Sherikov, C. Collette, D. Dimitrov, and P.B. Wieber, *A robust linear MPC approach to online generation of 3D biped walking motion*, IEEE-RAS International Conference on Humanoid Robots (Seoul, KR), 2015, pp. 595-601.

4. Products

International Conference Publications

P1. D. Serra, A.C. Satici, F. Ruggiero, V. Lippiello, and B. Siciliano, *An optimal trajectory planner for a robotic batting task: The table tennis example*, International Conference on Informatics in Control, Automation and Robotics (Lisbon, PT), 2016, pp. 90–101. **Nominated for Best Student Paper Award**
P2. D. Serra, *Robot control for nonprehensile dynamic manipulation tasks*, International Conference on Informatics in Control, Automation and Robotics, Doctoral Constortium (Lisbon, PT), 2016, pp. 3–12. **Best Ph.D. Project Award**
P3. D. Serra, C. Brasseur, A. Sherikov, D. Dimitrov, and P.B. Wieber, *A Newton method with always feasible iterates for Nonlinear Model Predictive Control of walking in a multi-contact situation*, IEEE–RAS International Conference on Humanoid Robots (Cancun, MX), 2016, pp. 932–937.
P4. D. Serra, A. C. Satici, F. Ruggiero, V. Lippiello, and B. Siciliano, *Time–optimal paths for a robotic batting task*, Springer Lecture Notes in Electrical Engineering, 2017, *to appear*.

Working Paper

P5. D. Serra, F. Ruggiero, V. Lippiello, and B. Siciliano, *A nonlinear least squares approach for nonprehensile dual-hand robotic ball juggling*, 2017.

5. Conferences and Seminars

- Presentation of the paper [P1] at the International Conference on Informatics in Control, Automation and Robotics (ICINCO), held in Lisbon (Portugal), 29-31 July, 2016.
- Presentation of the paper [P2], and of the related poster, at the ICINCO Doctoral Consortium, held in conjunction with the ICINCO conference in Lisbon (Portugal).
- Presentation of the research activities about multi-contact walking nonlinear model predictive control at INRIA Grenoble Rhone-Alpes (FR), to the Bipop team. September 29, 2016.
- Presentation of the paper [P3] at the IEEE International Conference on Humanoid Robots, Cancun (Mexico), 15-17 November, 2016.

6. Activity Abroad

Diana Serra has spent a six months' period, from the 4th of April 2016 to the 3rd of October 2016, as visiting PhD student at the Institut National de Recherche en Informatique et en Automatique (INRIA), Grenoble Rhone-Alpes (FR), in the Bipop team, under the supervision of the Research Director Pierre-Brice Wieber. The collaboration with Pierre-Brice Wieber has taught the theoretical framework behind modeling and control of bipedal robotic walking. The research carried on during this period is about nonlinear model predictive control approaches to multi-contact bipedal humanoid walking. Diana Serra has been invited to present her research activities in a talk given at INRIA, on the 29th of September, 2016. The research has lead to the publication of a conference paper [P3], which has been presented by Diana Serra at the 16th IEEE-RAS International Conference on Humanoid Robots, held in Cancun (Mexico).

7. Tutorship

- Tutorship for the course of *Istituzioni di Analisi Matematica e Geometria*, 9 hours. Corso di laurea in Scienze dell'Architettura, Università degli Studi di Napoli Federico II.
- Co-Advisor for two master theses about nonprehensile manipulation planning and control methods, entitled *Dynamic Non-Prehensile Manipulation: Application to Ball Juggling*, and *Planning and Control the Reconfiguration of a Sphere Rolling on a Plate Actuated by a Robot* (in Italian). Corso di laurea in Ingegneria dell'Automazione, Università degli Studi di Napoli Federico II.