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 – Second Year

Tutor: Vincenzo Lippiello

1. Information

Diana Serra, MS in Automation Engineering – Università di Napoli Federico II

XXIX Cycle - ITEE – Università di Napoli Federico II

Fellowship named “Controllo di Robot per la Manipolazione Dinamica”, funded by the CREATE consortium - Consorzio di Ricerca per l’Energia e le Applicazioni dell’Elettromagnetismo.

Tutor: Prof. Vincenzo Lippiello

2. Study and Training activities

Courses

- Ad hoc module: “English course”, 01.2015 – 06.2015, 6 credits.
- Ad hoc module: “Designing and writing scientific manuscripts for publication in English language scholarly journals, and related topics”, 15.06.2015 – 17.06.2015, 3 credits.

Seminars

- “MPC for plasma magnetic control”, by Prof. S. Gerksic, 24.03.2015, 0.6 credits.
- “Observability of switched systems”, by Prof. S. Trenn, 30.03.2015, Università del Sannio, Benevento, 0.3 credits.
- “Controllability of switched systems”, by Prof. S. Trenn, 01.04.2015, Università del Sannio, Benevento, 0.3 credits.
- “Colloquium on Robotics Six Keynote Talks by International Experts”, by Prof. O. Khatib, Prof. T. Asfour, Prof. R. Lumia, Prof. G. Indiveri, Prof. K. Kyriakopoulos, Prof. R. Madhavan, 21.04.2015, 1 credit.
- “On Abel Differential Equations of the 2nd Kind and Exact Inversion of Boost DC/AC converters”, Dr J. Olm, 13.05.2015, 0.2 credits.
- Seminar and project on “Passivity-based control of nonlinear physical systems: A port-Hamiltonian approach”, by PhD A. Donaire, 27.05.2015, 2 credits.
- “On Motion Planning, Motion Representation and its Orbital Stabilization for Mechanical System”, by Prof. A. Shiriaev, 12.11.2015, 0.2 credits.
- “Real-Time Embedded Control Systems”, by Prof. G. Buttazzo, 16.11.2015, 1.2 credits.
- “Test and Diagnosis of Integrated Circuits”, by Prof. A. Bosio, 17-18.11.2015, 2.4 credits.
- “Hardware Security and Trust”, Prof. G. Natale, 19-20.11.2015, 2.4 credits.
- “Armi autonome: problemi etici e decisioni politiche”, by Prof. G. Tamburrini, 01.12.2015, 0.4 credits.

External courses

Summer School about “Robot Control”, organized by SIDRA (Società Italiana Docenti e Ricercatori in Automatica), 07.2015, held in Bertinoro (FC), Italy, coordinated by Prof. A. De Luca, (website of the school: www.lar.dei.unibo.it/SIDRA2015/index.php/2015-03-31-16-08-17/robot-control).

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

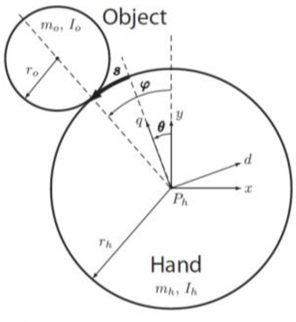
Student: Diana Serra — diana.serra@unina.it | **Tutor: Vincenzo Lippiello** — vincenzo.lippiello@unina.it | **Cycle XXIX**

	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	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	18	10-30
Research	34	9	1	4	3	9	7,8	34	42	7	1	8	11	9	10	46	52							0	80	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	0	0	0	0	0	0	0	128	180

3. Research activity

Nonprehensile Manipulation Primitives Control

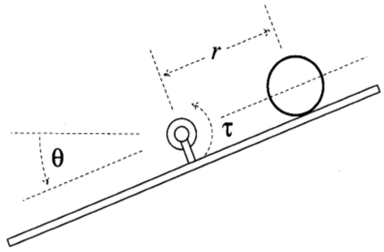
The robotic manipulation problem aims at finding a set of suitable controls to change the configuration of an object from an initial to a desired value. Such manipulation task is achievable in a nonprehensile and dynamic way, i.e. without grasp and exploiting the task dynamics in the control design. Since a



Disk on disk system

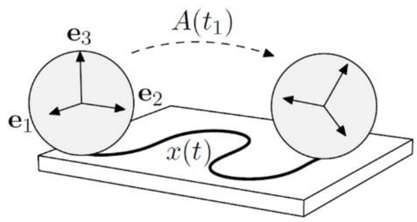
nonprehensile task is complicated, skilful and dexterous, it is typically split in many simpler subtasks, usually named *primitives*, such as rolling, pushing, throwing, batting, etc. The primitives related to the research activity carried out during the second year of my PhD, are the planar and three-dimensional rolling and the batting primitive. In particular, I have inspected the passivity based control method applied to the planar rolling manipulation of two arbitrary shapes, the problem of position and orientation control of a rolling ball acted by an underlying moving plate [P1], and an optimum planner for the batting task applied to the table tennis game [P2].

- The Port-Hamiltonian framework allows modelling of mechanical systems, preserving physical phenomenon information. This has the advantage to represent the model as a general nonlinear system, suitable for the application of passivity based control methods. The goal of this work is the application of Interconnection and Damping Assignment Passivity Based Control (IDA-PBC) to the planar rolling manipulation between two arbitrary shapes. As assumption, one shape is actuated (hand), while the other one is free to move (object). The object is restricted to roll without sliding on the hand. This is a nonprehensile system, since no grasp is involved to position the object through the hand, and then a disturbance applied to the object is able to change the system configuration. The IDA-PBC control law renders the closed loop as a desired Port-Hamiltonian system. Assuming constant mass matrix for the system, I have proposed an energy shaping control law that contains the arclength parametrization of the object/hand shapes. The balancing of a disk free to roll on an actuated disk (*disk on disk* system) is the case study considered to validate this approach, since in this system the assumption of constant inertia is valid. Moreover, removing the simplifying assumption of constant mass matrix, a new method to derive an IDA-PBC control law, relevant to this kind of rolling underactuated system, is inspected. The approach employs a target Potential Energy Matching Equation (PE-ME) which is an additional degree of freedom to select a suitable desired energy function for the closed loop system, and simultaneously to simplify the recognition of the desired closed loop mass matrix. The procedure is employed to control a ball rolling on a beam without sliding (*ball and beam* system), which is another benchmark nonprehensile manipulation system. Even if the ball and beam is a simple planar system, it is not feedback linearizable; this distinctive property encourages investigating new control frameworks to stabilize it.



Ball and beam system

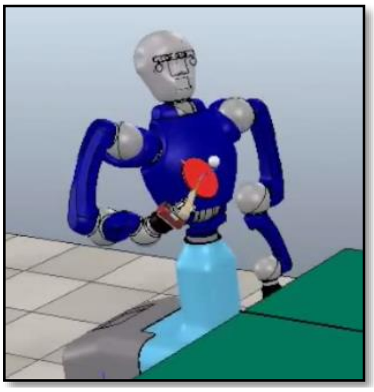
- The robotic nonprehensile manipulation of a rolling ball is a challenging task because of the nonholonomic constraint induced by the non-twist and non-slipping conditions. In addition, this system is not asymptotically stabilizable with a smooth or time-invariant feedback because the Brockett's necessary condition is not satisfied. A dynamic model of the ball and plate system is derived according to the Boltzmann-Hamel equations, taking into account the nonholonomic constraint. A controllability analysis reveals that the whole dynamics is not controllable, only a linear relation exists between ball position and plate position. Whereas, the ball dynamics is controllable. Therefore, a geometric planning and control method is implemented to steer the rolling ball between two arbitrary position and orientation configurations. The algorithm previously computes the ball position, velocity and acceleration trajectories to reach a desired



3D rolling primitive

configuration, after computes a feedback control to track the path planned for the ball. The design of an extended Kalman filter allows estimating the ball orientation, which is relevant to check the correctness of the results. The experimental validation employing a robotic platform is a current research activity.

- The batting task combines catching and throwing in a single collision. The table tennis game requires such ability. This task requires so high velocities and precision that robotic companies take it as an example to display the high performances of their products. A method to compute the paddle state to return the ball at a desired position with a desired spin, well suited for real-time execution, is implemented. The method takes into account the dynamic model of the ball in free flight as well as the state transition at the impact (the reset map). An optimal motion planner is designed for the paddle to reach the desired configuration. The optimal trajectory minimizes the acceleration functional, solving a two boundary value problem on SE(3). Simulations show the results through a comparison with state-of-the-art methods.



Application of the batting task to the table tennis game: simulation in V-REP environment.

- Future research directions:
  - Application of the control method developed for planar rolling to other case studies. Currently, I am investigating the application of this approach to the *circular ball and beam* system, which is another benchmark nonprehensile manipulation system. The stabilization of such a system is challenging, as compared to conventional ball and (straight) beam system, due to the presence of two unstable equilibrium points and the gyroscopic forces appearing in its dynamics.
  - Experimental validation of the control method for the 3D rolling manipulation primitive employing a real robotic platform.

<u>Collaborations</u>

- Involved in the ERC Advanced Grant RODYMAN (RObotic DYnamic MANipulation) project, http://www.rodyman.eu/.
- Forthcoming collaboration with the BiPoP team at INRIA (Grenoble, France) to learn about nonsmooth systems, and to transfer concepts between dynamic manipulation and walking robots.

4. Products

<u>Publications in preparation</u>

[P1] "*Robotic nonprehensile manipulation of a rolling ball*".

[P2] "*An Optimal Trajectory Planner for a Robotic Batting Task: The Table Tennis Example*".

5. Conferences and Seminars

- Participation to the 2015 IEEE/RSJ Conference on Intelligent Robots and Systems, 28.09.2015 – 02.10.2015, held in Hamburg, Germany, (website of the conference: http://www.iros2015.org/).
- Participation to the Workshop/Tutorial about "Robotics System Toolbox from MathWorks", at 2015 IROS conference, 02.10.2015, in Hamburg, Germany.

6. Tutorship

- Tutorship to two master students for their master thesis in Automation Engineering. The first work has the objective to model, control and simulate the batting task. The other thesis has the objective to inspect the juggling rhythmic task, to study some control approaches. Support to design an extended Kalman filter for visual data processing in the tracking of a ball in free flight.
- Tutorship for students of the "Scuola Politecnica e delle Scienze di Base" at University of Naples Federico II.
  - Tutorship for the course of "Analisi Matematica I e Geometria", at Architecture 5UE Degree Course, 24 hours,
  - Tutorship for the course of "Istituzioni di Analisi Matematica e Geometria" at Architecture Science Degree Course, 17 hours.