Università degli Studi di Napoli Federico II

PhD program in

Information Technology and Electrical Engineering

PhD Student: Viviana Morlando

Cycle: XXXV

Training and Research Activities Report

Academic year: 2020-21 - PhD Year: Second

*__student signature_*

Tutor: Dr. Ing. Fabio Ruggiero

*__tutor signature_*

Date: October 21, 2021

1. Information:

- **PhD student: Viviana Morlando** **PhD Cycle: XXXV**
- **DR number: DR993891**
- **Date of birth: 26/06/1996**
- **Master Science degree: Automation Engineering** **University: Università degli Studi di Napoli Federico II**
- **Scholarship type: DIETI PRIN 2017 "PRINBOT"**
- **Tutor: Fabio Ruggiero**

2. Study and training activities:

Activity	Type[1]	Hours	Credits	Dates	Organizer	Certificate[2]
Robot Manipulation and Control	**Seminar**	**2 h 30 min**	**0.5**	**17/11/2020**	**Prof. Bruno Siciliano**	**Y**
Antonio Picariello Lectures on DataScience, "Digital Project Management: Practices, processes, techniques, tools and scientific Approach"	**Seminar**	**1 h**	**0.2**	**18/11/2020**	**Prof. Flora Amato, Prof. Giuseppe Longo**	**Y**
L'esperienza del progetto di tele-riabilitazione NEUROREAB	**Seminar**	**3 h**	**0.6**	**24/11/2020**	**Ing. D. Furno e Ing. L. Romanelli**	**Y**
Antonio Picariello Lectures on DataScience, "#andràtuttobene: Images, Texts, Emojis & Geo-data in aSentiment Analysis Pipeline"	**Seminar**	**1 h 30 min**	**0.3**	**25/11/2020**	**Prof. Flora Amato, Prof. Giuseppe Longo**	**Y**

IEEE Webinar "Patent Searching best practices with IEEE Xplore"	Seminar	1	0.2	27/11/2020		Y
Antonio Picariello Lectures on Data Science, "At the Nexus of Big Data, Machine Intelligence, and Human Cognition"	Seminar	1	0.2	02/12/2020	Prof. Flora Amato, Prof. Giuseppe Longo	Y
Scientific Colloquia at SSM, Network Systems, Kuramoto Oscillators, and Synchronous Power Flow	Seminar	1 h 30 min	0.3	03/12/2020	Prof. Francesco Bullo	N
Antonio Picariello Lectures on Data Science, "Exploiting Deep Learning and Probabilistic Modeling for Behavior Analytics"	Seminar	1 h	0.2	09/12/2020	Prof. Flora Amato, Prof. Giuseppe Longo	Y
Antonio Picariello Lectures on Data Science, "Data driven transformation in WINDTRE through Managers voice"	Seminar	2 h	0.4	16/12/2020	Prof. Flora Amato, Prof. Giuseppe Longo	Y
Study of legged manipulators and realization of a framework for nonprehensile transportation of an object with legged robots	Research		6	01/11/2020 - 31/12/2020		
Antonio Picariello Lectures on DataScience, "From Photometric Redshifts to Improved Weather Forecasts, an interdisciplinary view on	Seminar	1 h	0.2	13/01/2021	Prof. Flora Amato, Prof. Giuseppe Longo	Y

machine learning”						
Antonio Picariello Lectures on DataScience, “Cybercrime and e-evidence: the criminal justice response”	**Seminar**	**2 h**	**0.4**	**20/01/2021**	**Prof. Flora Amato, Prof. Giuseppe Longo**	**Y**
Antonio Picariello Lectures on Data Science, “AI: Artificial Intelligence for notary's sector - a case study”	**Seminar**	**1 h**	**0.2**	**27/01/2021**	**Prof. Flora Amato, Prof. Giuseppe Longo**	**Y**
"Advances in Machine Learning for Modelling and Understanding in Earth Sciences"	**Seminar**	**1 h**	**0.2**	**27/01/2021**	**Prof. Gustau Camps-Valls**	**Y**
“IFRR Colloquium on Quadruped Robotics”, http://ifrr.org/quadruped-robotics	**Seminar**	**2 h**	**0.4**	**04/02/2021**	**International Foundation of Robotics Research**	**N**
Antonio Picariello Lectures on Data Science, “Machine Learning: causality lost in traslation”	**Seminar**	**1 h 30 min**	**0.3**	**10/02/2021**	**Prof. Flora Amato, Prof. Giuseppe Longo**	**Y**
Antonio Picariello Lectures on Data Science, “Approaches to Graph Machine Learning”	**Seminar**	**1 h**	**0.2**	**17/02/2021**	**Prof. Flora Amato, Prof. Giuseppe Longo**	**Y**
Study of legged manipulators and realization of a framework for nonprehensile transportation of an object with legged robots - Preparation of the	**Research**		**8**	**01/01/2021 - 28/02/2021**		

paper "Whole-body Control with Disturbance Rejection through Momentum-based Observer for Quadruped Robots" submitted to "Mechanism and Machine Theory"						
Scientific Programming and Visualization with Python	**Courses**		**3**	**8/03/2021-10/03/2021**	**Prof. Alessio Botta**	**Y**
Statistical data analysis for science and engineering research	**Courses**		**4**	**17-19-24-25/02/03-04/03/2021**	**Prof. Roberto Pietrantuono**	**Y**
Antonio Picariello Lectures on DataScience, "Visual Interaction and Communication in Data Science"	**Seminar**	**2 h**	**0.4**	**03/03/2021**	**Prof. Flora Amato, Prof. Giuseppe Longo**	**Y**
Robo Ludens: A game design taxonomy for human-robot interaction	**Seminar**	**1 h**	**0.2**	**05/03/2021**	**Prof. Silvia Rossi**	**Y**
Antonio Picariello Lectures on DataScience, "Big Data and Computational Linguistics"	**Seminar**	**2 h**	**0.4**	**10/03/2021**	**Prof. Flora Amato, Prof. Giuseppe Longo**	**Y**
Artificial Intelligence and 5G combined with holographic technology: a new perspective for remote health monitoring	**Seminar**	**2 h**	**0.4**	**27/04/2021**	**Dr. Pietro Ferraro, Dr. Pasquale Memmolo**	**N**
Revision of the paper "Whole-body Control with Disturbance Rejection through Momentum-based Observer for	**Research**		**5**	**01/03/2021 - 30/04/2021**		

Quadruped Robots" submitted to "Mechanism and Machine Theory" - Work on the realization and the simulation of a framework for nonprehensile transportation with legged robots						
Introduction to Underwater Robotics	**Seminar**	**2 h**	**0.4**	**18/05/2021**	**Dr. Fabio Ruggiero**	**N**
Introduction to legged robots and examples of IIT's Dynamic Legged Systems Lab	**Seminar**	**2 h**	**0.4**	**26/05/2021**	**Dr. Fabio Ruggiero**	**N**
Revision of the paper "Whole-body Control with Disturbance Rejection through Momentum-based Observer for Quadruped Robots" published in "Mechanism and Machine Theory" - Realization and simulations of a framework for nonprehensile transportation with a quadruped robot for the paper "Nonprehensile Transportation of an object with a legged manipulator" to submit	**Research**		**8**	**01/05/2021 - 30/06/2021**		
SIDRA 2021 PhD Summer School – "Game Theory and Network	**Doctoral School**	**30 h**	**4**	**12/07/2021 - 17/07/2021**	**Prof. Claudio Melchiorri**	**Y**

Systems" and "Modeling and Control of Soft Robots" - Bertinoro University Residential Centre – July 12-17 2021					**- Prof. Maria Elena Valcher**	
Preparation of the paper "Nonprehensile Transportation of an object with a legged manipulator" to submit to RAL. Preparation of the paper "Disturbance rejection for legged robots through a hybrid observer" to submit to ICRA conference	**Research**		**7**	**01/07/2021 - 31/08/2021**		
Preparation of the paper "Nonprehensile Transportation of an object with a legged manipulator" submitted to RAL. Preparation of the paper "Disturbance rejection for legged robots through a hybrid observer" submitted to ICRA conference. Study on the dynamic and control of a guide dog robot.	**Research**		**10**	**01/09/2021 - 31/10/2021**		

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**	**2.9**	**6**	**0**	**8.9**
Bimonth 2	**0**	**1.9**	**8**	**0**	**9.9**
Bimonth 3	**7**	**1.4**	**5**	**0**	**13.4**

Bimonth 4	**0**	**0.8**	**8**	**0**	**8.8**
Bimonth 5	**4**	**0**	**7**	**0**	**11**
Bimonth 6	**0**	**0**	**10**	**0**	**10**
Total	**11**	**7**	**44**	**0**	**62**
Expected	**30 – 70**	**10 - 30**	**80 - 140**	**0 – 4.8**	

3. Research activity:

My scholarship is associated with the project PRIN 2017 "PRINBOT - Grapevine Recognition and Winter Pruning Automation Based on Innovative Robots (20172HHNK5_002)", which aims to develop innovative robotic technologies for grapevine winter pruning automation. My research activity focuses on controlling legged robotic systems, creating a control architecture for a legged locomotion platform endowed with a robotic arm, walking on different terrain, and performing manipulation tasks

For this reason, during this 2nd year, my research can be divided into two activities.

1st activity : Robust locomotion on irregular terrains

One of the main objectives of service robotics is developing autonomous systems able to move in unstructured environments. Regarding autonomous locomotion, significant differences exist between wheeled systems and legged ones. While wheeled robots can move at high speeds, useful to cover an ample space in a short time, they encounter severe difficulties in traversing uneven terrain and environments designed for human use, like steps and stairs. These problems can be solved using legged robots, which can walk through challenging terrain, adapt their foothold to its irregularities, and overcome obstacles lifting the leg.

The problem addressed by the project associated with this Ph.D. research focuses on quadruped robots since they have higher stability than biped robots. At the same time, their legs are more manageable to coordinate than robots with six or more legs. Different control solutions have been proposed over the years to achieve dynamic locomotion for a quadruped robot. The best approach is considering the entire dynamic of the robot using a whole-body control or a model predictive control (MPC). While the first one allows the decoupling of the motion planning from the controller [1-3], the last one can stabilize the robot by predicting the movements over a finite horizon [4,5], despite the difficulty of the nonlinearity of the legged robot dynamics. In both cases, online re-planning is possible, which contributes to coping with the roughness of the terrain and all the external disturbances. Since this kind of robot has started to be used for inspection or patrolling in unstructured environments full of obstacles, the robot needs to retain its balance and adapt its foothold to the roughness of the terrain and reject external disturbances. In some cases, these disturbances are considered with the use of an observer. However, the literature reports observers that only consider the disturbances applied directly either on the center of mass or on the support legs [3,6], without considering a more comprehensive range of disturbances present in more complex situations.

During the first Ph.D. year, the research was focused on the development of a whole-body controller based on the decoupling of the centroidal's dynamics (the dynamics of the center of mass) from the legs' ones, composed of a quadratic problem (QP) that modules the ground reaction forces to retain balance during the locomotion. As a solution to the problem of the external disturbance, the realization of a momentum-based observer has been faced. Different from other observers, this one, inspired by [7], also considers the disturbances acting on legs that are still swinging. In this way, the robot can work under challenging conditions such as in difficult atmosphere situations or in narrow spaces where it is easy to have a collision between a leg that is still moving and the environment. The observer's estimation has been combined with the whole-body controller to be tested in the "Gazebo simulator", where the platform used is DogBot, provided by React Robotics (https://reactrobotics.com).

However, this observer deploys the leg's dynamics, neglecting the centroidal's ones. This approximation might be crucial whenever the robot is stressed by major forces acting directly on the CoM. For this reason, during this 2nd year of Ph.D., following this path, a new hybrid observer dealing with disturbances acting both on the CoM and on the legs is presented.

The estimation of the external wrench acting on the CoM has found wide applications [6], [8]. In most cases, a momentum-based observer is employed, requiring the CoM's translational velocity knowledge. Usually, such a velocity is indirectly obtained through a transformation presented in [9] and not directly from a sensor. An inertial measurement unit (IMU) is typically mounted on moving robots such as legged, aerial, or wheeled robots. This sensor provides the floating base's angular velocity and translational acceleration, leaving the translational velocity to a numerical estimation. For a legged robot, using the centroidal's dynamics, there is the need first to compute the floating base's translational velocity and then transform it into the CoM's translational velocity.

These computations, alongside the approximation made to obtain the centroidal's dynamics, can bring significant mistakes in estimating the external wrench. For this reason, differently from the literature, the proposed hybrid estimator comprises three different components:

1. The first one deals with the CoM's translational part.
2. The second component copes with the CoM's angular part.
3. The third one regards the legs.

This last exploits what was realized during the 1st year, presented in [10], dealing with disturbances applied to both swing and stance legs. The first and second components are instead designed to adopt a hybrid observer. Such a hybrid observer comprises a momentum-based observer for CoM's angular term and an acceleration-based observer for the CoM's translational one, employing directly measurable values from the IMU. Therefore, here, with hybrid, it is intended to combine of two different kinds of observers, the momentum-based and the acceleration-based. Tracking of the desired CoM's trajectory is preserved as the rejection of a foot's drift. The resulting control architecture is thus different from existing approaches, which can guarantee either the CoM's tracking or the drift's rejection only. The devised hybrid observer is integrated into a whole-body controller, consisting of a suitable motion planner decoupled from the optimization problem. As in the previous case, the observer was tested in the "Gazebo simulator", where the platform used is DogBot, provided by React Robotics.

2nd activity: Nonprehensile transportation with a legged manipulator

Service robots are developed to assist human beings in performing typically dull, dangerous, or repetitive tasks, including household chores. The robot must navigate in a usually broad but cluttered environment and solve other complex tasks such as grasping, manipulating, and transporting objects. For this reason, the research in service robotics has been directed, over the years, towards mobile manipulators, able to both traverse large spaces and execute manipulation tasks. Most mobile robots developed in the last years are wheeled robots endowed with one or two manipulator arms, usually designed to support older people in their daily lives by providing independent living support and remote assistance. These robots can execute complex manipulation tasks such as opening a door or picking items from shelves [11].

However, wheeled robots often encounter difficulties in unstructured environments with non-flat grounds limiting their application range. Instead, legged robots can overcome these obstacles by effectively sensing and adapting their steps to the ground.

Nevertheless, although their performance can vastly exceed those of wheeled robots in unstructured and challenging environments, legged robots still need to find their space in the service fields of household or hospitality. To widen their spectrum of applications, the recent trend is to endow multi-legged robots with arms that make them capable of grasping and manipulating objects [12] enabling interaction-based tasks such as opening a hinged door [13].

Despite their unique and handy features, current legged robots have never been shown before capable of nonprehensile manipulation tasks. Nonprehensile manipulation can be reasonably considered the most complex manipulation task [14]. In a nonprehensile manipulation task, it is neither possible to prevent infinitesimal motions of the object nor to resist all external wrenches applied to it. The capability of performing a nonprehensile manipulation, in principle, would enable legged robots to achieve a broader range of dexterous manipulation tasks, the simplest one being object transportation.

Regarding this aspect, the research of the second year of this Ph.D. has been focused on developing an optimization-based whole-body control architecture for a legged robot transporting an object on a tray in a nonprehensile configuration. The proposed controller takes into account both nonprehensile manipulation and locomotion constraints in a unified and principled way. The faced problem regarded the transportation of an object from an initial to a goal pose without firmly grasping it using a legged robot endowed with a manipulator arm. Locomotion and manipulation tasks present similar non-sliding constraints that need to be satisfied to transport the object safely. Carrying a payload modifies the dynamics of the robot, which, in turn, must not only counteract but also regulate its motion to satisfy these ground and object non-sliding constraints jointly.

The realized controller has been tested in the "Gazebo simulator", where the platform used is DogBot, provided by React Robotics, suitably modified, endowing it with an arm.

[1] C. D. Bellicoso, F. Jenelten, P. Fankhauser, C. Gehring, J. Hwangbo, and M. Hutter, “Dynamic locomotion and whole-body control for quadrupedal robots,” in 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). IEEE, 2017, pp. 3359–3365.

[2] C. D. Bellicoso, F. Jenelten, C. Gehring, and M. Hutter, “Dynamic locomotion through online nonlinear motion optimization for quadrupedal robots,” IEEE Robotics and Automation Letters, vol. 3, no. 3, pp. 2261– 2268, 2018.

[3] S. Fahmi, C. Mastalli, M. Focchi, and C. Semini, “Passive whole-body control for quadruped robots: Experimental validation over challenging terrain,” IEEE Robotics

[4] G. Bledt, P. M. Wensing, and S. Kim, “Policy-regularized model predictive control to stabilize diverse quadrupedal gaits for the mit cheetah,” in 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). IEEE, 2017, pp. 4102–4109.

[5] M. Neunert, M. Stauble, M. Giftthaler, C. D. Bellicoso, J. Carius, C. Gehring, M. Hutter, and J. Buchli, “Whole-body nonlinear model predictive control through contacts for quadrupeds,” IEEE Robotics and Automation Letters, vol. 3, no. 3, pp. 1458–1465, 2018.

[6] M. Focchi, R. Orsolino, M. Camurri, V. Barasuol, C. Mastalli, D. G. Caldwell, and C. Semini, “Heuristic planning for rough terrain locomotion in presence of external disturbances and variable perception quality,” in Advances in Robotics Research: From Lab to Market. Springer, 2020, pp. 165–209.

[7] F. Ruggiero, J. Cacace, H. Sadeghian, and V. Lippiello, “Passivity-based control of vtol uavs with a momentum-based estimator of external wrench and unmodeled dynamics,” Robotics and Autonomous Systems, vol. 72, pp. 139–151, 2015.

[8] J. Englsberger, G. Mesesan, and C. Ott, “Smooth trajectory generationand push-recovery based on divergent component of motion,” in2017IEEE/RSJ International Conference on Intelligent Robots and Systems,2017, pp. 4560–4567.

[9] C. Ott, M. A. Roa, and G. Hirzinger, “Posture and balance controlfor biped robots based on contact force optimization,” in2011 11thIEEE-RAS International Conference on Humanoid Robots.IEEE,2011, pp. 26–33.

[10] V. Morlando, A. Teimoorzadeh, and F. Ruggiero, “Whole-body control with disturbance rejection through a momentum-based observer for quadruped robots,” Mech. Mach. Theory, vol. 164, p. 104412, 2021.

[11] S. Chitta, B. Cohen, and M. Likhachev, “Planning for autonomous door opening with a mobile manipulator,” in Proc. IEEE Int. Conf. Rob. Autom., 2010, pp. 1799–1806.

[12] C. D. Bellicoso, K. Kramer, M. St¨auble, D. Sako, F. Jenelten, M. Bjelonic, and M. Hutter, “Alma-articulated locomotion and manipulation for a torque-controllable robot,” in Proc. IEEE Int. Conf. Robot. Autom., 2019, pp. 8477–8483.

[13] P. Sleiman, F. Farshidian, M. V. Minniti, and M. Hutter, “A unified mpc framework for whole-body dynamic locomotion and manipulation,” IEEE Robot. Autom. Lett., vol. 6, no. 3, pp. 4688–4695, 2021.

[14] F. Ruggiero, V. Lippiello, and B. Siciliano, “Nonprehensile dynamic manipulation: A survey,” IEEE Robot. Autom. Lett., vol. 3, no. 3, pp.1711–1718, July 2018.

4. Research products

V. Morlando, A. Teimoorzadeh, F. Ruggiero, "Whole-body control with disturbance rejection through a momentum-based observer for quadruped robots", published in Mechanism and Machine Theory 164, 2021, DOI: 10.1016/j.mechmachtheory.2021.104412 .

V. Morlando, M. Selvaggio, F. Ruggiero, " Nonprehensile Object Transportation with a Legged Manipulator", submitted to Robotics and Automation Letters (IEEE RAL), 2022

V. Morlando, F. Ruggiero, " Disturbance rejection for legged robots through a hybrid observer", submitted to IEEE International Conference on Robotics and Automation 2022 (ICRA 2022)

5. Conferences and seminars attended

6. Periods abroad and/or in international research institutions

7. Tutorship

Tutorship for Carmela Mariniello’s B.Sc. thesis in Automation Engineering.
Tutorship for Salvatore Punzo’s M.Sc. thesis in Automation Engineering.

8. Plan for year three

1. Long-term visit at the Dynamic Legged Systems Lab, Italian Institute of Technology, Genova (15/11/2021-31/01/2022): working on the implementation and testing of a disturbance observer for a quadruped robot endowed with an arm.
2. Planning a research period abroad : ETH Zurich, Robotic Systems Lab headed by Marco Hutter (February 2022 – July 2022).
3. Draft topic of the thesis: Robust control for the locomanipulation of a quadruped robot endowed with an arm
4. Further research topic: modelling and control of a guide dog quadruped robot.