PhD student Viviana Morlando

Disturbance rejection in optimal control for limbed parallel robots

Tutor: Prof. Fabio Ruggiero

Cycle: XXXV Year: Third

Background information

- M.Sc. in Automation Engineering Università degli Studi di Napoli Federico II
- Group: PRISMA Lab
- PhD start date: 1/11/2019
- PhD end date: 31/01/2023
- Scholarship type: DIETI PRIN 2017 "PRINBOT“
- Periods in a company: 15/11/2021-31/01/2022 Dynamic Legged System, IIT
- Periods abroad: 01/04/2022-30/09/2022 Robotics System Lab, ETH Zurich

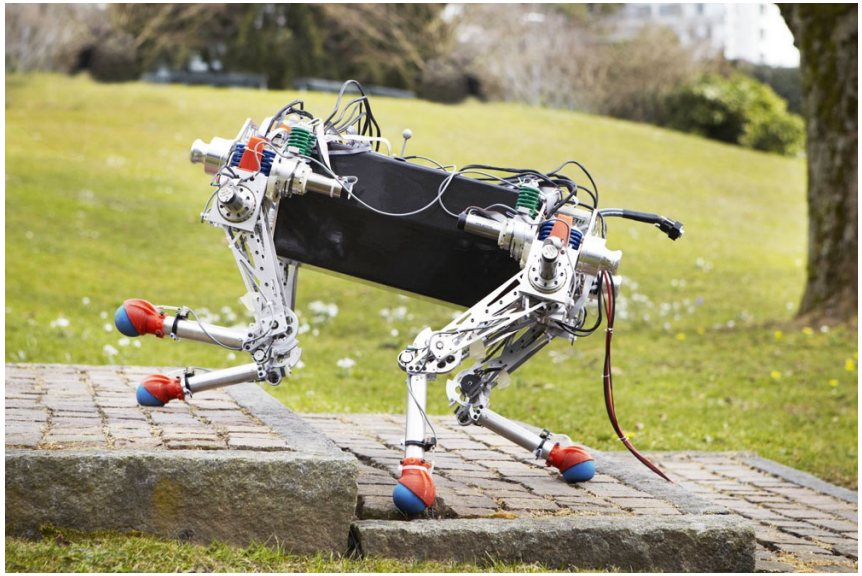
Summary of study activities

- **Ad hoc PhD courses / schools:**
  - Machine Learning
  - Scientific Programming and Visualization with Python
  - EECI- International Graduate School on Control 2020- M10 Model Predictive Control, Remote
  - SIDRA 2021 PhD Summer School, Bertinoro University Residential Centre

- **Courses attended borrowed from MSc curricula**
  - Field and service robotics
  - Robotics Lab

- **Conferences attended**
  - 2022 International Conference on Robotics and Automation (ICRA), Philadelphia, Pennsylvania, 23/05/2022-27/05/2022
  - Conferenza I-RIM 3D 2022, 4 Conferenza Italiana di Robotica e Macchine Intelligenti Roma, Italia, 7/10/2022-9/10/2022

Research area



- Objective: robust control of autonomous systems in unstructured environments
- Importance of limbed parallel robots: can move in challenging terrains and overcome obstacles
- Open challenges for limbed parallel robots: intrinsecally unstable and easily subject to external disturbances

Research products

[P1]	**Viviana Morlando**, Ainoor Teimoorzadeh, Fabio Ruggiero "Whole-body control with disturbance rejection through a momentum-based observer for quadruped robots", *Mechanism and Machine Theory*, vol. 164 , pp. 104412, 2021, DOI: https://doi.org/10.1016/j.mechmachtheory.2021.104412
[P2]	**Viviana Morlando**, Mario Selvaggio, Fabio Ruggiero "Nonprehensile Object Transportation with a Legged Manipulator", *2022 International Conference on Robotics and Automation (ICRA),* Philadelphia, Pennsylvania, May 2022, pp. 6628-6634, IEEE, DOI: 10.1109/ICRA46639.2022.9811810
[P3]	**Viviana Morlando**, Fabio Ruggiero "Disturbance rejection for legged robots through a hybrid observer", *2022 30th Mediterranean Conference on Control and Automation (MED)* Athens, Greece, June 2022, pp. 743-748, IEEE, DOI: 10.1109/MED54222.2022.9837169
[P4]	**Viviana Morlando** , Mario Selvaggio, Fabio Ruggiero "Robotic Non-prehensile Object Transportation", *Conferenza I-RIM 3D 2022*, 4 Conferenza Italiana di Robotica e Macchine Intelligenti Roma, Italia, Oct. 2022

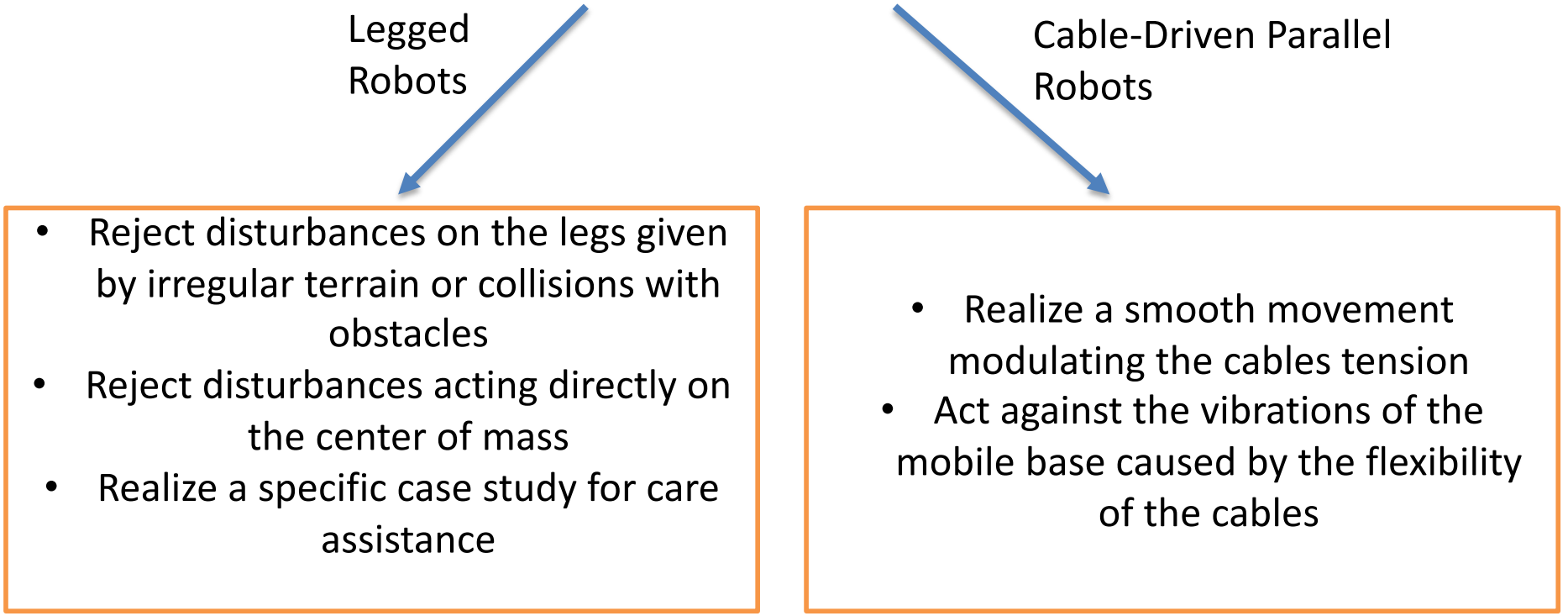
[P5]	**Viviana Morlando**, Fabio Ruggiero “Tethering a Human with a Quadruped Robot: A Guide Dog to Help Visually Impaired People”, Submitted to 2023 IEEE International Conference on Robotics and Automation, London, United Kingdom, 2023
[P6]	**Viviana Morlando**, Gianluca Neglia, Fabio Ruggiero, “Drilling task with a quadruped robot for silage face measurements,” Submitted to the 2023 IEEE International Workshop on Measurements and Applications in Veterinary and Animal Sciences, Naples, Italy, 2023
[P7]	**Viviana Morlando**, Till Karbacher, Salman Faraji, Marco Hutter “An MPC framework for an underconstrained floating cable-driven robot” Submitted to “Robotics and Automation Letters”

PhD thesis overview (1/3)

- Problem statement
  - Control of limbed parallel robots able to work in challenging environments
  - Legged robots: easily subject to disturbances given by irregularities in the terrain
  - Cable-driven robots: easily subject to disturbances and irregular movements given by the flexibility of the cables

PhD thesis overview (2/3)

- Objective
  - Realization of framework able to improve performance of limbed parallel robots against disturbances



PhD thesis overview (3/3)

- Methodology
  - Optimal control solutions

Legged Robots

Disturbance Observer Based Whole-Body Controller
- Estimation of forces acting on the legs
- Estimation of forces acting on the center of mass

Cable-Driven Parallel Robots

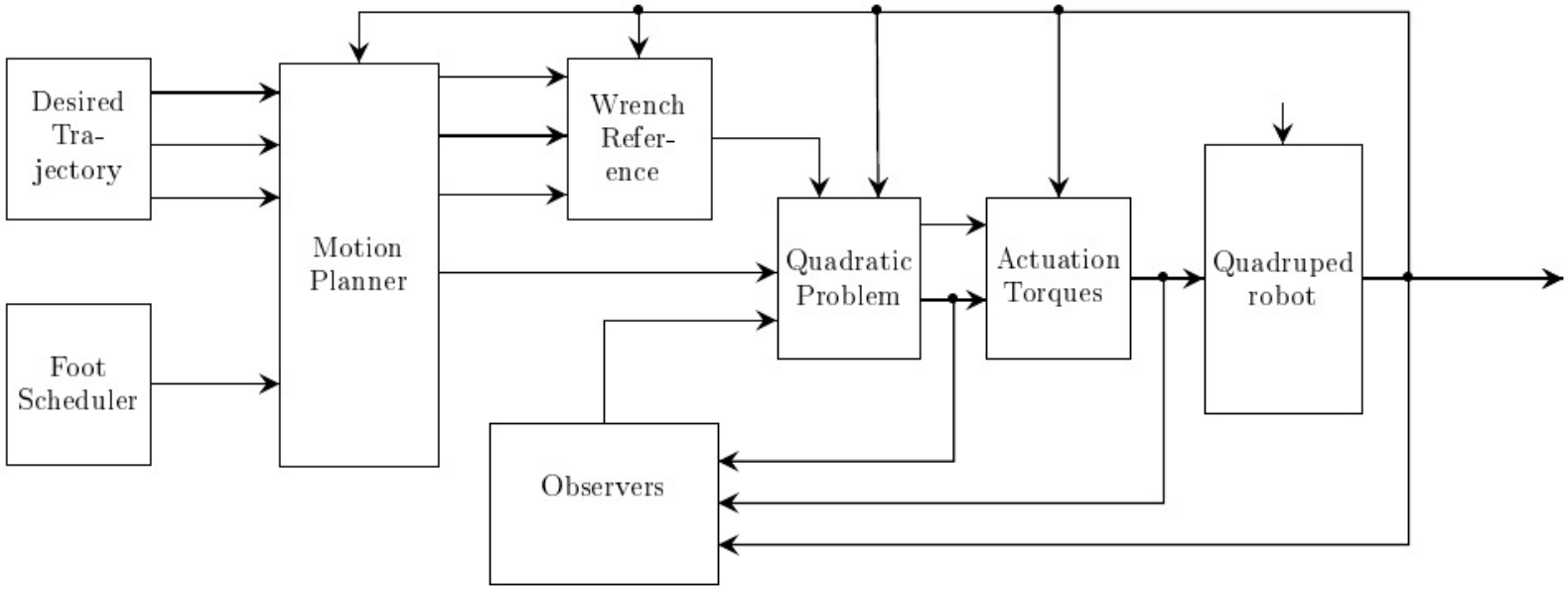
Model Predictive Control
- Using a wrench-based problem to modulate the cables tension
- Minimize the oscillations of the base given by the flexibility of the cables

PhD thesis

- ***Robust locomotion for legged robots***
  - *Retain the balance*
  - *Adapt foothold to the roughness of the terrain*
  - *Reject external disturbances*

PhD thesis

- ***Proposed solution:*** *Whole-body control with disturbance observers*
- ***Methodologies:***
  - *Decouple the centroidal's dynamics (the dynamics of the center of mass) from the legs' ones*
  - *Consider the disturbances acting both on the center of mass and on the swing and stance legs*



PhD thesis

- ***Novelties:***
  - *Disturbances acting on the swing legs are explicitly addressed*
  - *A hybrid observer is used for the center of mass, composed of two different kinds of observers, a momentum- and an acceleration-based*
  - *Only directly measurable values from the IMU are employed in the hybrid observer*

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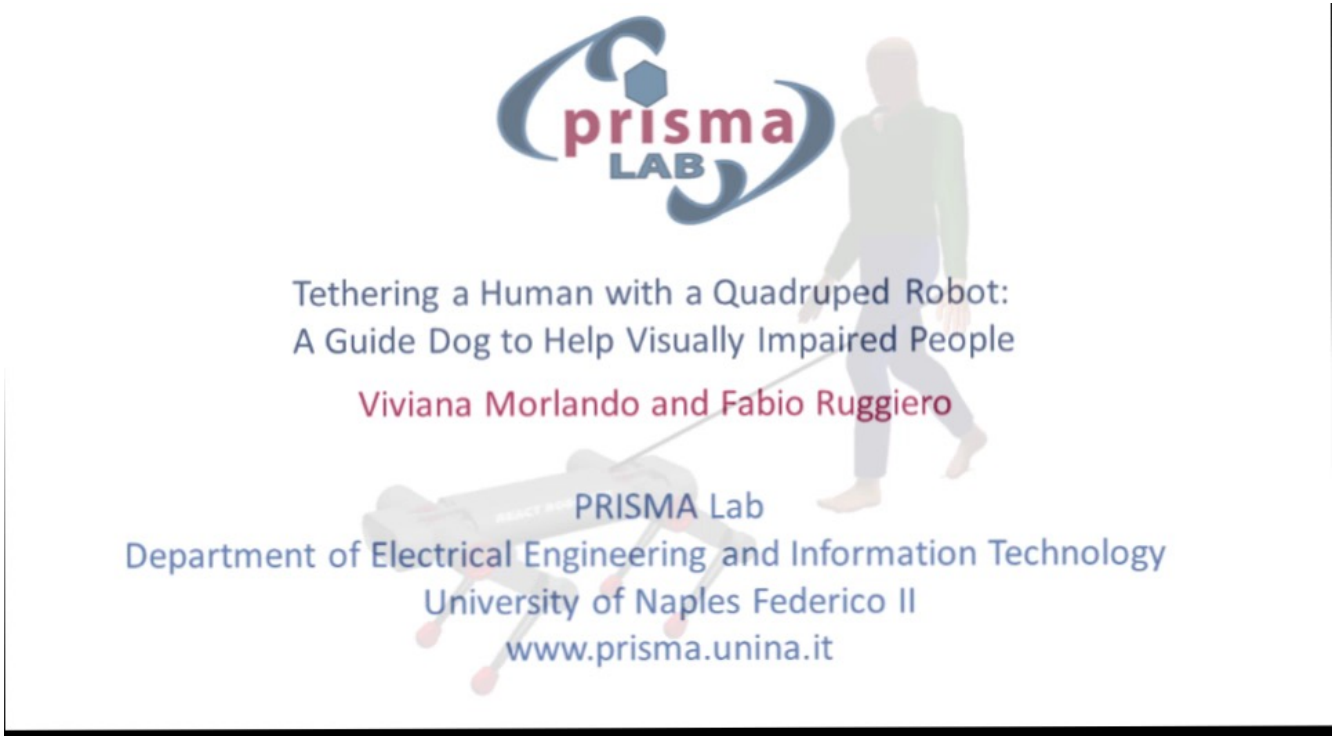
Case study

Highlights:

- Two random disturbances are applied: the first acting on the CoM and the second acting on a randomly chosen point of one of the legs
- The force's magnitude changes randomly between ***2.5 N*** and ***40 N*** every four seconds
- Tested in presence of noisy measurements, additive white Gaussian noise: Std Dev = 10%

PhD thesis

- ***A guide dog to help visually impaired people***
  - *The quadrupedal robot is enabled to guide a human through a leash*
  - *The observer is employed to retrieve information about the tension of the leash*
  - *A supervisor is realized based on the interaction force measured through the observe*



PhD thesis

- ***Model predictive control (MPC) for cable-driven robots***
  - *Realize a smooth movement modulating the cables tension*
  - *Minimize oscillations caused by the flexibility of the cables*
  - *Reject external disturbances*

PhD thesis

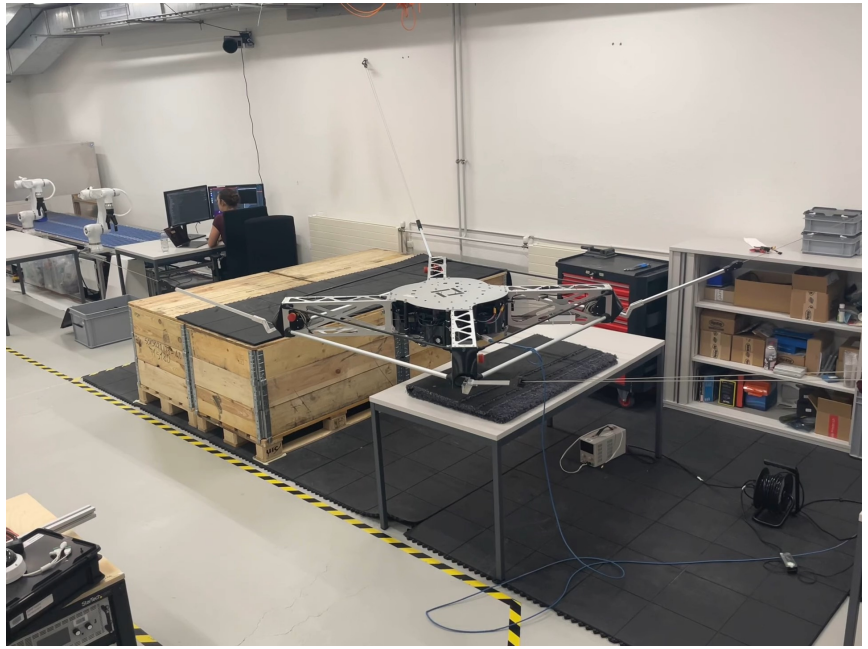
The floating manipulator has been developed at the Robotic System Lab, ETH Zurich. Considering its main characteristics, it is:

- A cable-driven robot
- Suspended at four poles
- Designed for gardening application
- An underactuated robot: 4 DoFs

PhD thesis

- ***Novelties:***
  - *A model predictive controller for an underconstrained cable-driven parallel robot*
  - *Centroidal dynamics are employed*
  - *A smooth movement with damped oscillations is obtained*

Without MPC



Using MPC

Thank you for your attention!