Research Presentation

Michele Focchi

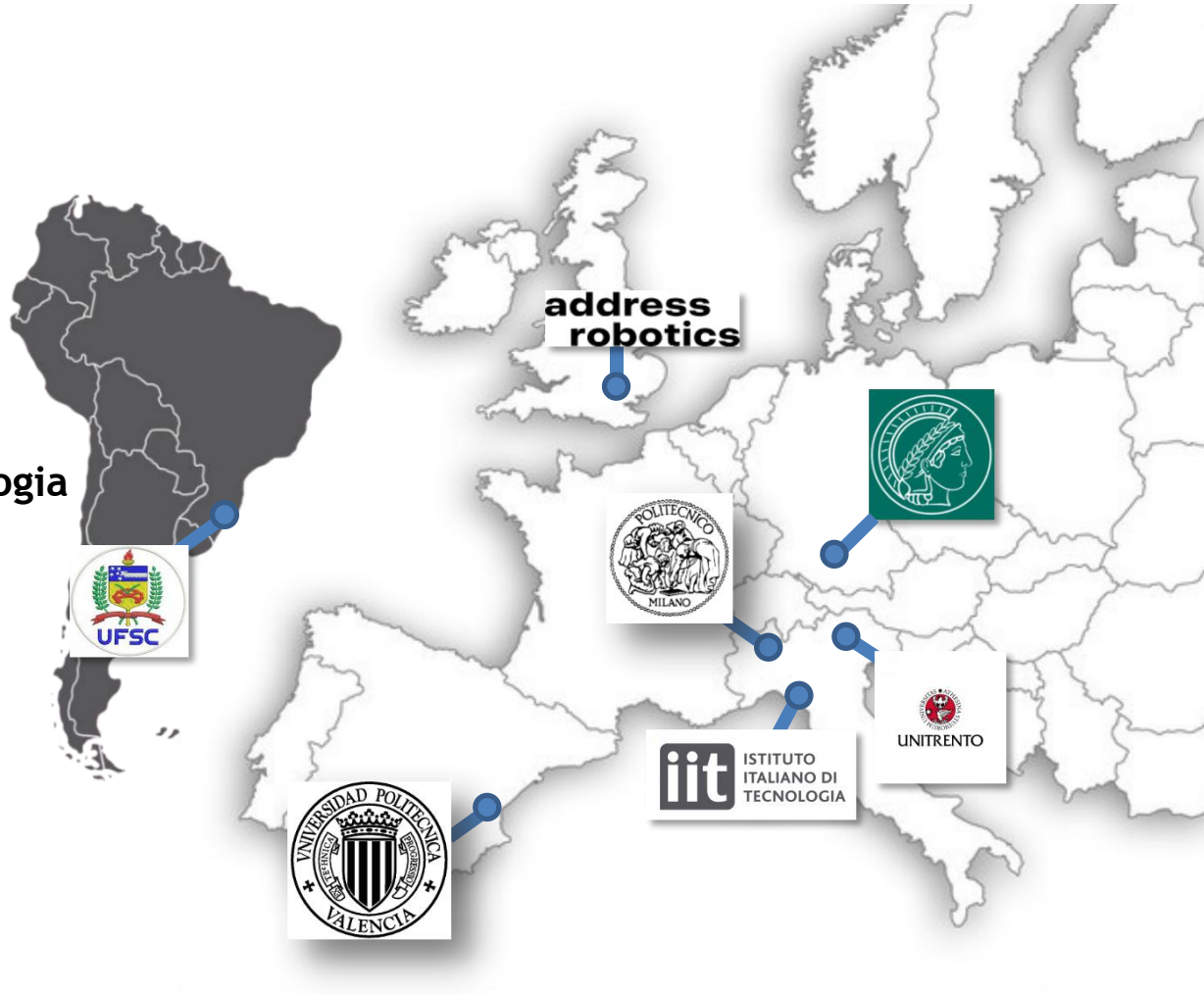
13/09/2024

Outline

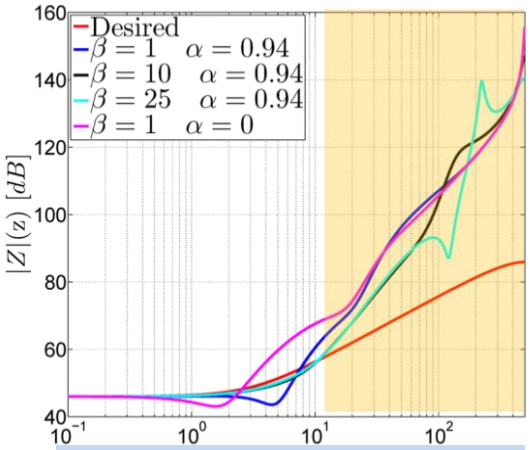
- Academic Curriculum
- Teaching
- Projects and Grants
- Technology Transfer
- Research Highlight
- Future Research

My Academic Journey

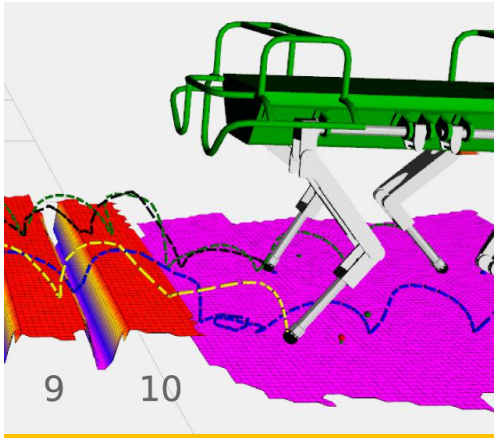
- 2021-now
  Assistant Professor (RTDA)
  University of Trento
- 2013
  PhD Internship
  Max Plank institute
- 2010-2021
  PhD / Researcher
  Università di Genova
  Istituto Italiano di Tecnologia
- 2007
  MSc Thesis
  Universidade Federal de Santa Catarina
- 2005
  MSc Internship
  Universidad Politecnica de Valencia
- 2001-2007
  BSc / MSc
  Politecnico di Milano



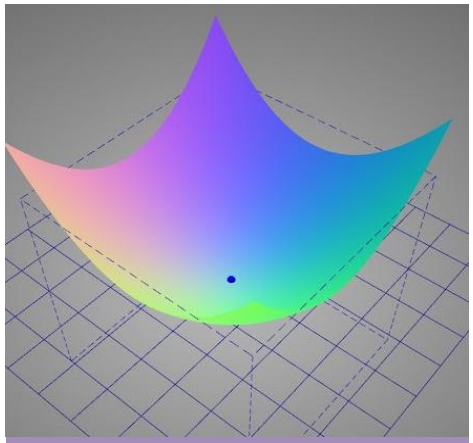
My Areas of Expertise



Control



Motion Planning



Numerical Optimization

Legged Robots

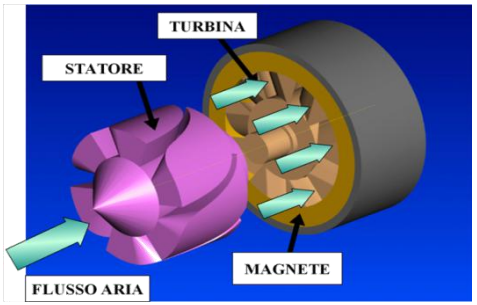
Field Robotics

Previous experiences

2008

2009

PATENT



2010

INDESIT company

R&D

iit ADVR

Fellow

Mictoturbine

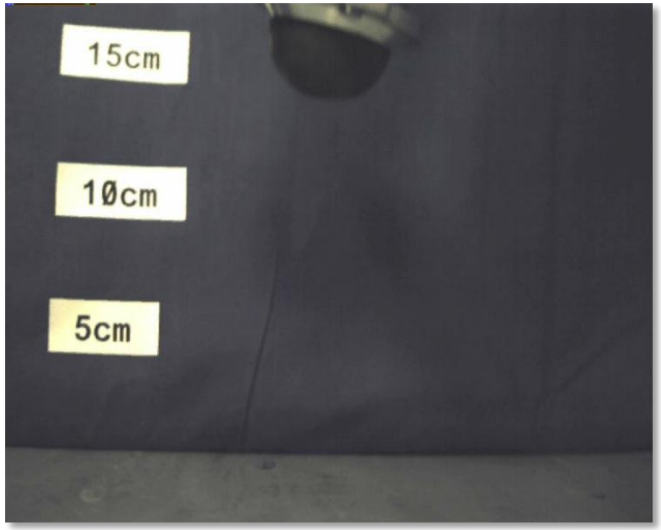
[TURBOEXPO 11]

SPIN OFF

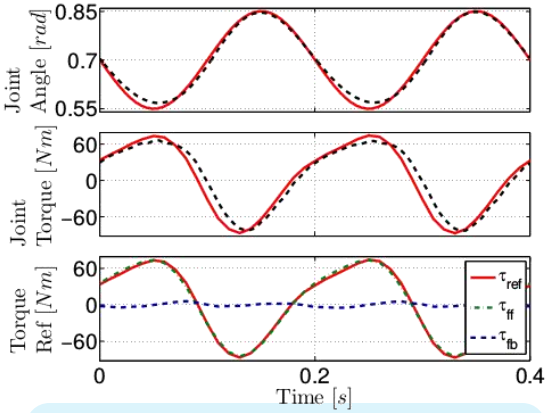
ADVANCED MICROTURBINES

Academic Career Overview

Magneto-rheological damper [JMD 14]

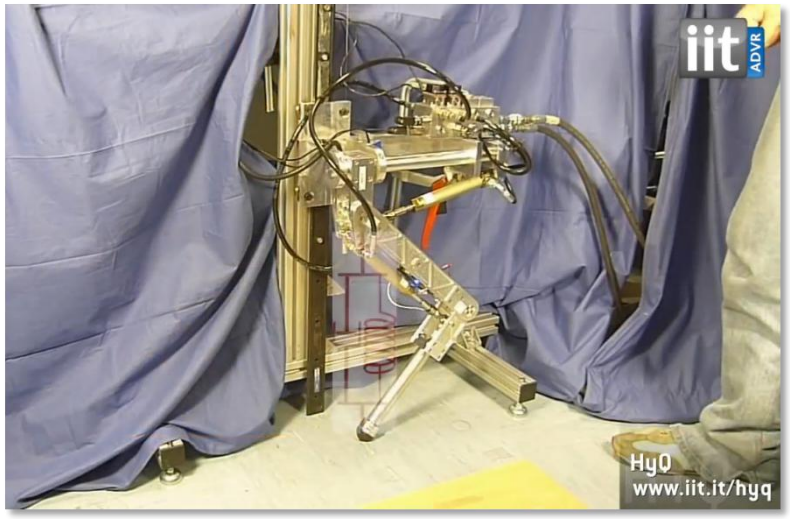


2010

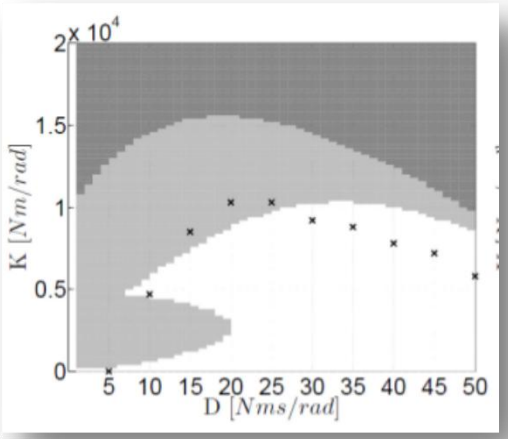


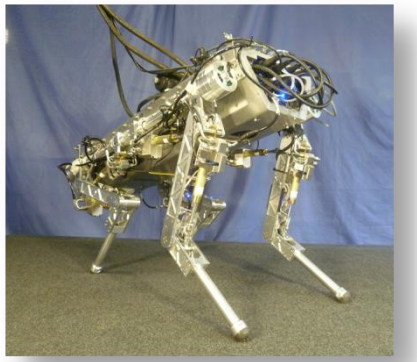
Hydraulic force control [ICRA 12]

PhD in robotics



Academic Career Overview



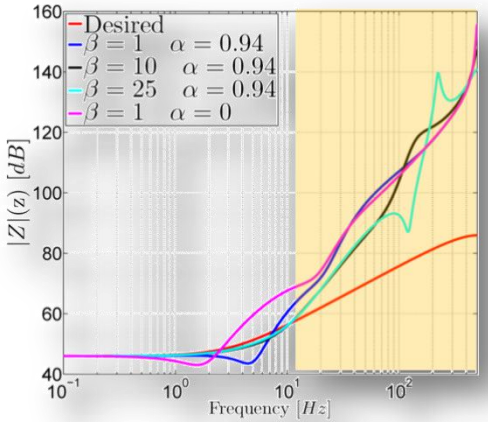


HyQ [JSCE 11]

2013 2014

iit ADVR

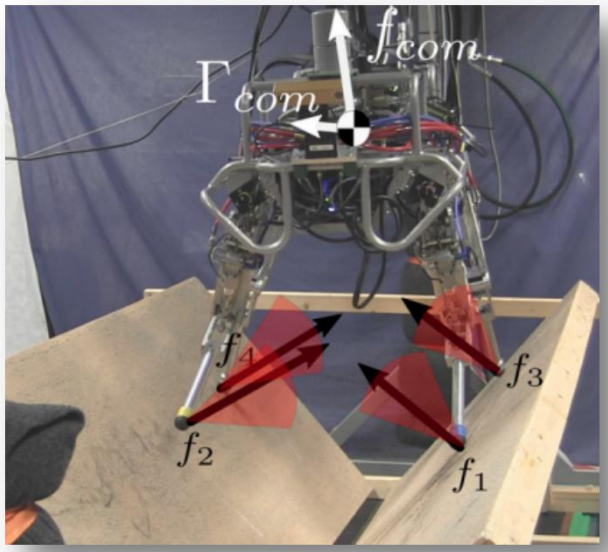
PhD
in robotics



Stability regions in Impedance Control [CTT 16]

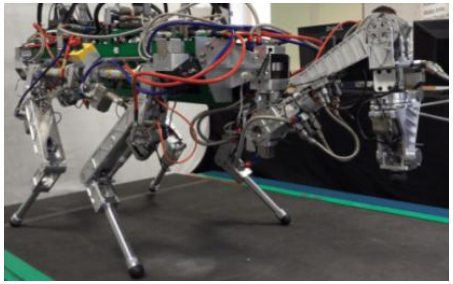
Whole-body control [AURO 17]

220 citations

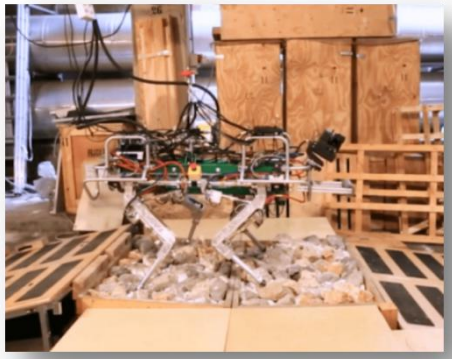


Academic Career Overview

2014



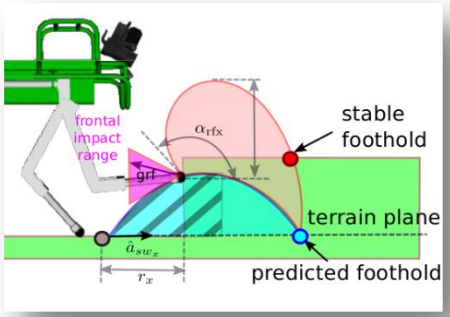
Control of HyQ-Centaur
[ICRA 16]



Heuristic planning
[SPRINGER 19]

HyQ2max
[TMECH 15]

Researcher



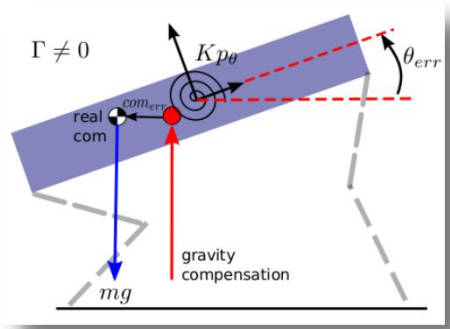
Step Reflex
[CLAWAR 13]

Slip detection &
recovery
[ISRR 15]

2015

Academic Career Overview

2015



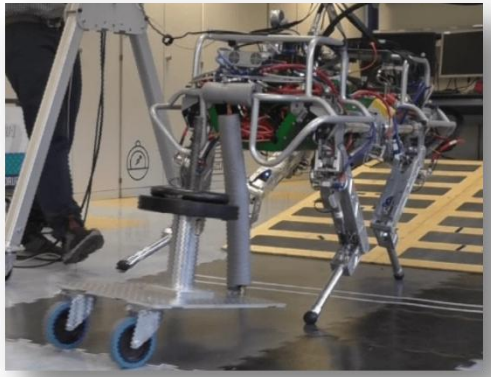
Online CoM Identification
[IROS 17]

Stair climbing
[SPRINGER 19]

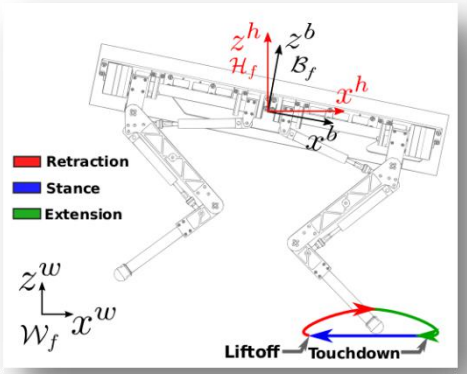
2017

iit DLS

Researcher



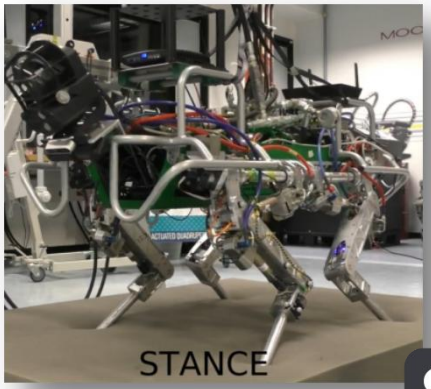
Disturbance Observer



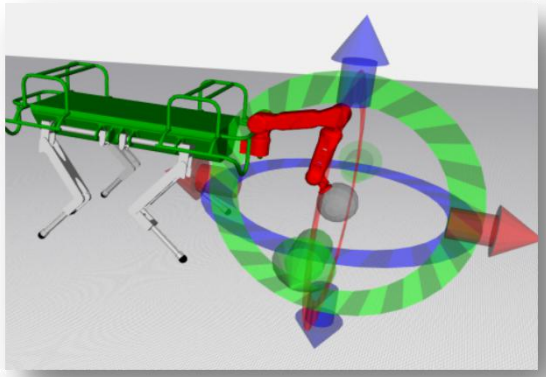
Bounding
[CLAWAR 17]

Academic Career Overview

Locomotion on soft-terrain [T-RO 19]



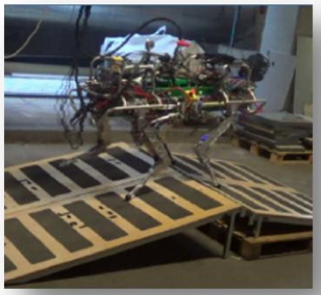
Hierarchical Whole-Body control [FRONTIERS 20]



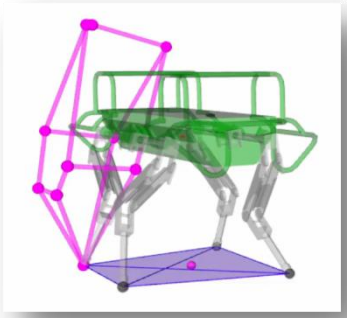
2017

Researcher

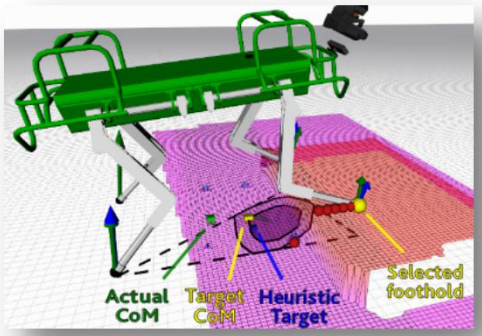
2018



Whole-body Control with actuation limits [RA-L 19]



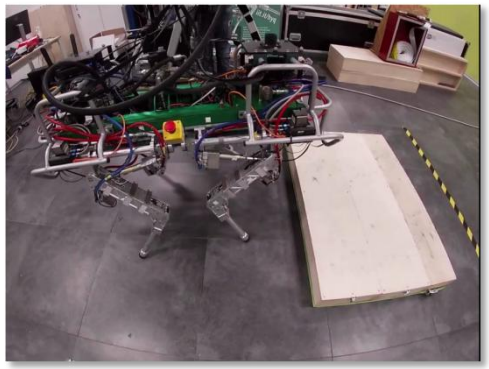
Wrench Polytope planning [RA-L 19]



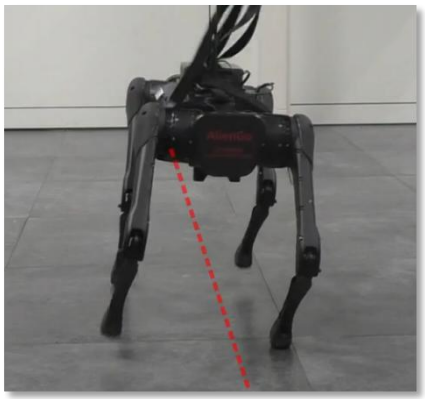
Feasible Region planning [T-RO 19]

HyqReal Robot

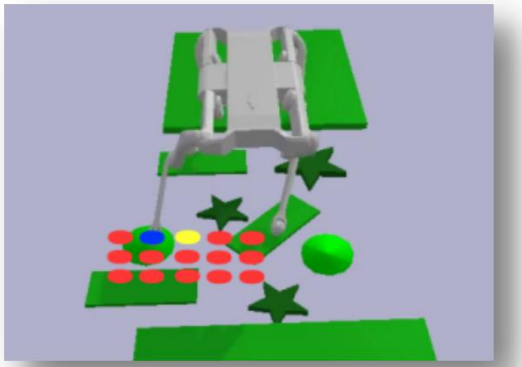
Academic Career Overview



NMPC plannning with mobility [IEEE Access 21]



Reference Generator for NMPC [Sensors 23]



Acyclic Foothold Planning [Ubiquitous Robots 24]

2018

Space - Non Wheeled all-terrain rover

iit DLS

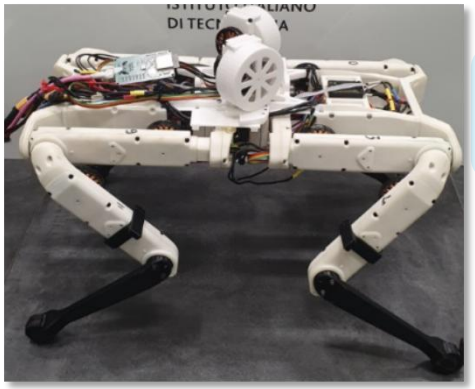
Researcher

INAIL

Tele-operation

2021

Academic Career Overview



Flight orientation Control [Sensors 23]

GPU based Guided RL for quadruped jumping

2021

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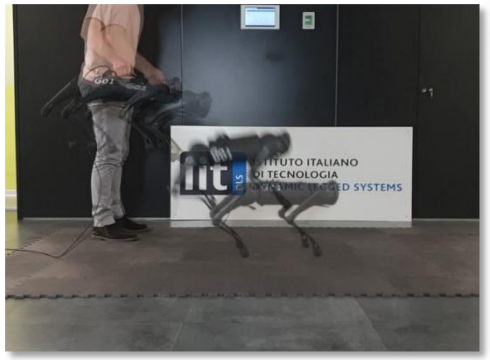
RTDA



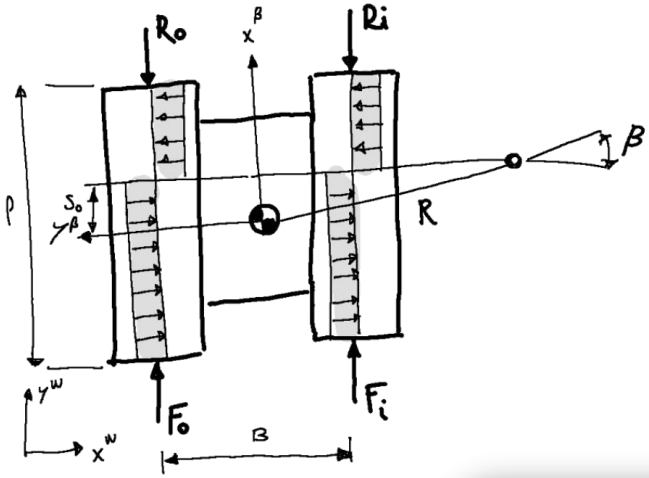
Landing controller [RA-L 23]

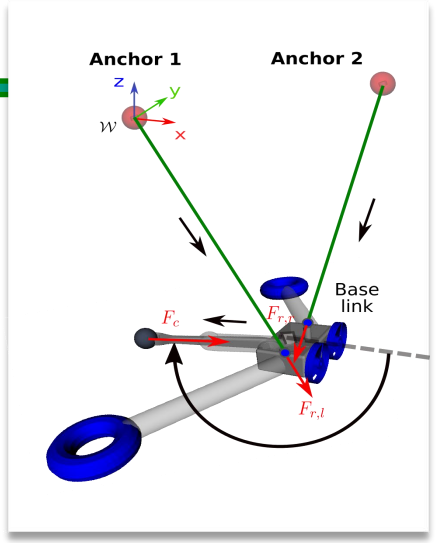
WOLF
WHOLE-BODY LOCOMOTION FRAMEWORK

2022

Locomotion Framework

Academic Career Overview





Rope-aided locomotion [ICRA 23]

2022

Digital agriculture [T-ASE 24] (2nd revision)

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RTDA

I-RIM/ERF: Dog Challenge Organizer

today

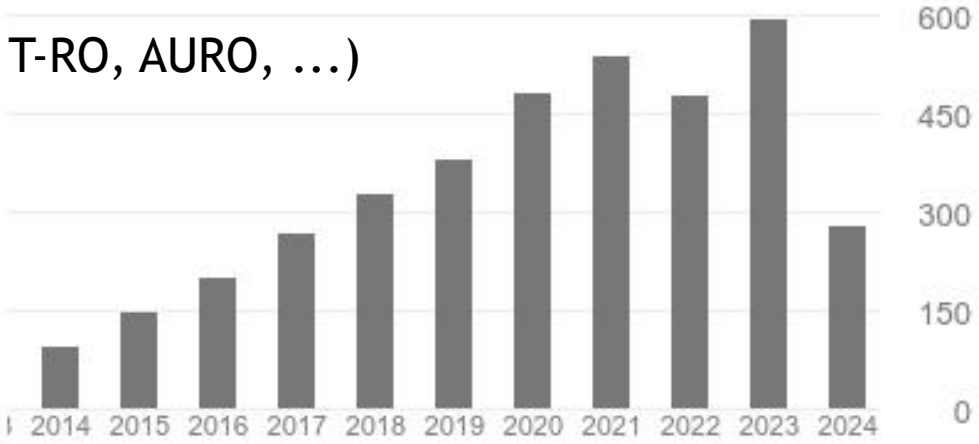
Academic Performance

Bibliometric indexes:

- H-Index: **31** (Scholar), 25 (Scopus)
- Citations: **3956** (Scholar), 2568 (Scopus)

52 papers:

- 9: **100+** citations
- 21 International journals (RA-L, T-RO, AURO, ...)
  - **9: ≤2° author**



Source Google Scholar (on 12/09/24)

Teaching & Student Supervision

Bachelor Courses (total 35 h):

- Foundation of Robotics (12 CFU, University of Trento)
- Fondamenti di Automatica (6 CFU, University of Trento)

Master Courses (total 90 h):

- Introduction to Robotics, in English (Chair, 6 CFU, University of Trento)

125 h

PhD Courses (total 26 h):

- Control of Legged Robots (Chair, University of Genova)
- Control of Legged Robots (Chair, University of São Paulo)

Teaching & Student Supervision

Research supervision:

- PhD cycles (**main**-supervision): **4**
- PhD cycles (co-supervision): **5**
- Master thesis: **9**

Lab Tutoring:

- Setting-up two robotics labs at UNITN
- Development of didactic framework for robot simulation: 250+ active users

LOCOSIM

github.com/mfocchi/locosim

- Practical lab activities

Grants and Projects

- EU FP7 - Echord++ (IIT), 2016-18, **300k€**

- Design and control of an autonomous quadruped platform

- INAIL (IIT), 2017-23, **5.4 M€**

- Enhance safety in hazardous environments

- European Space Agency - ANT (IIT), 2020-21,**400k€**

- Plantary exploration

- RECOARO (UNIBZ) (Provincial funds)

- Agricultural applications

Technology Transfer

- Micro-turbine for power generation

PATENT

IT 102018000002407

PRIZE

25k€

PNICube Innovation 2013

SPIN OFF

ADVANCED MICROTURBINES

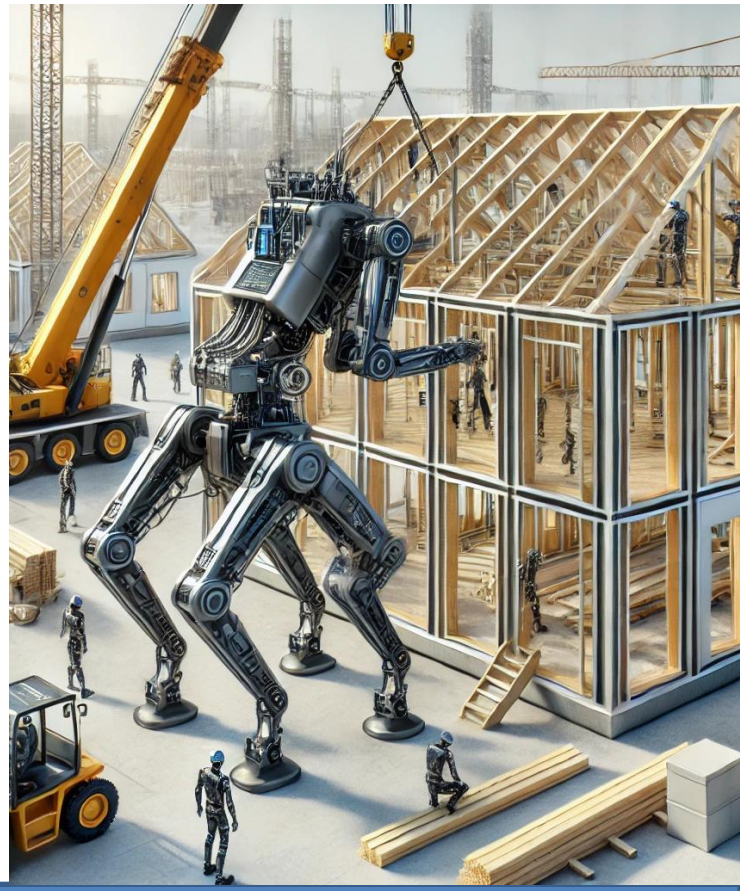
- Funding member of the MOOG-IIT **joint lab** (2015-21): 3M€ (inkind)

MOOG | iit ISTITUTO ITALIANO DI TECNOLOGIA

Robotics applied to Construction Cycle

- Scientific Advisor (since 2024) for Address Robotics, UK
- Build model based on data driven approach with enabling technologies to eliminate rework costs (real time architecture)

- Maximise premanufactured elements to reduce construction time and minimize CO_2 emissions
- Employ legged robots/automatic cranes:
  - To automatize the building process
  - For monitoring of construction progress



Miscellaneous Responsibilities

- Founding member (2014) of the **Dynamic Legged Systems** Research Line (IIT)
- Qualification for associate professor (ASN):
  - **ING-INF05**
  - ING-INF04
  - ING-IND13
- Editorial service
  - RA-L, ICRA, Frontier and AI Associate Editor
  - PhD panel board: 2
  - **ERC** Synergy grant reviewer
- Workshop: Organization (RSS, ICRA), Invited Speaker (ICRA, ICAR, I-RIM..)
- IEEE Senior Member

Dissemination

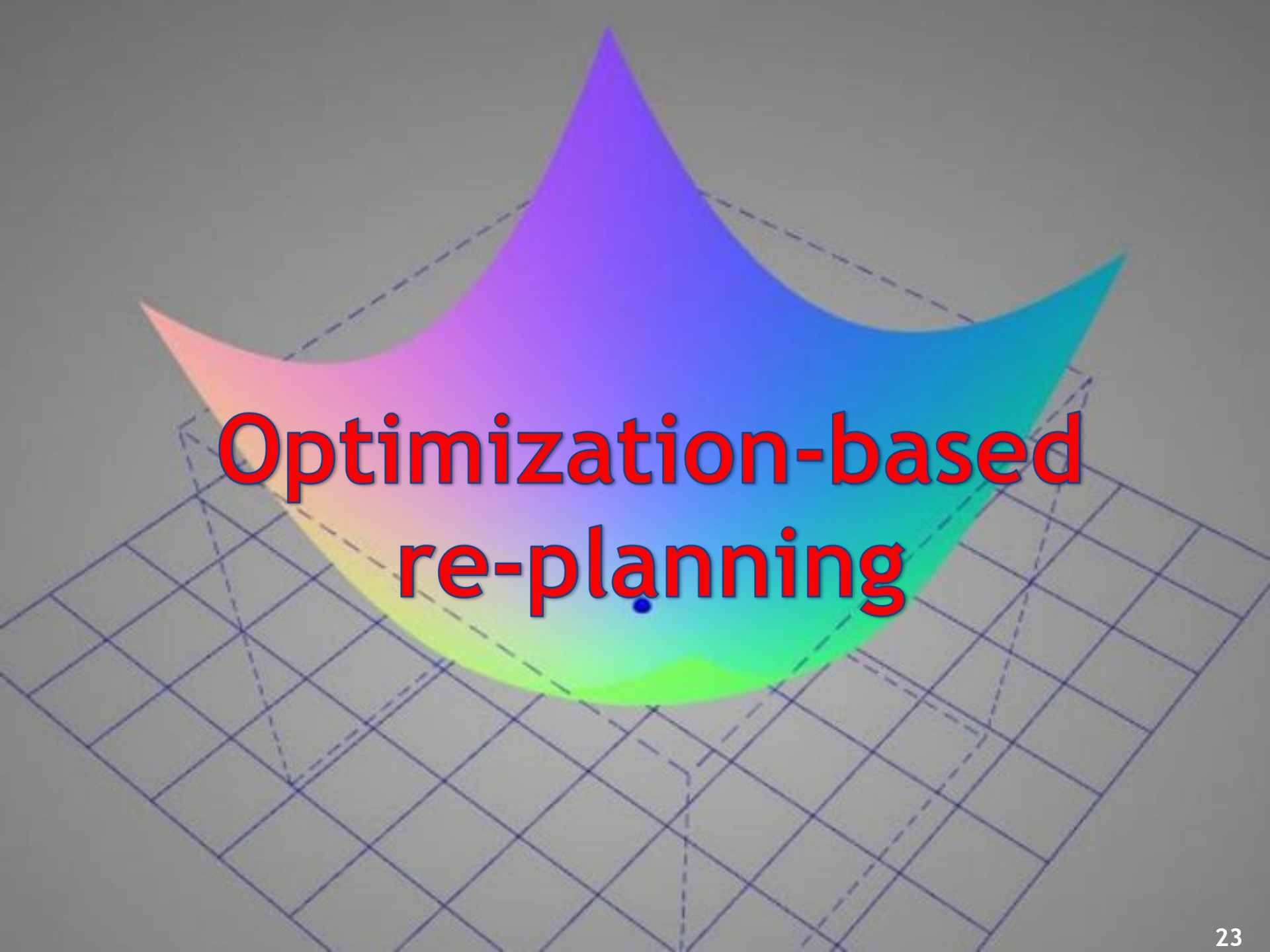
National TV interviews:

- TG5
- TGR leonardo
- **TG2**
- **TG3-pixel**
- ”Le iene”

Demos:

- Maker Faire, Rome (2019)
- HyQReal Pulling a plane,
  Genova airport (2019)
- ERF, Rovereto (2014)
- RSS, Rome (2015)


Research
Highlight


Optimization-based
re-planning

Optimization-based re-planning: pros and cons

- exploit models to predict future robot behavior
- be generic for any kind of gait / terrain
- quickly recover from planning errors (simplified model, terrain changes, disturbances)
- accommodate to velocity set-point set by the user

PLANNING HORIZON

to have anticipative behavior

✗ **problem size increases**

RE-PLANNING FREQUENCY

to mitigate error accumulation and be reactive

DENSITY OF DISCRETIZATION

to capture main robot dynamics

✗ **problem size increases**

✓ **trade-off bw accuracy and computation time**

Lower dimensional models motivation

C2 Many Degrees of Freedom → Computation time explodes with number of states / constraints

C3 Unstable Dynamics → Need fast reaction time

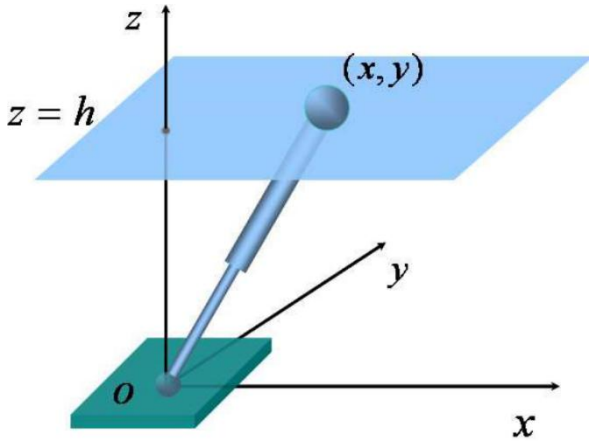
Lower dimensional models:

- Capture only the predominant dynamics
- Limited number of states
- Linear/ moderate non linearity

Optimization is faster (can then be carried out online)

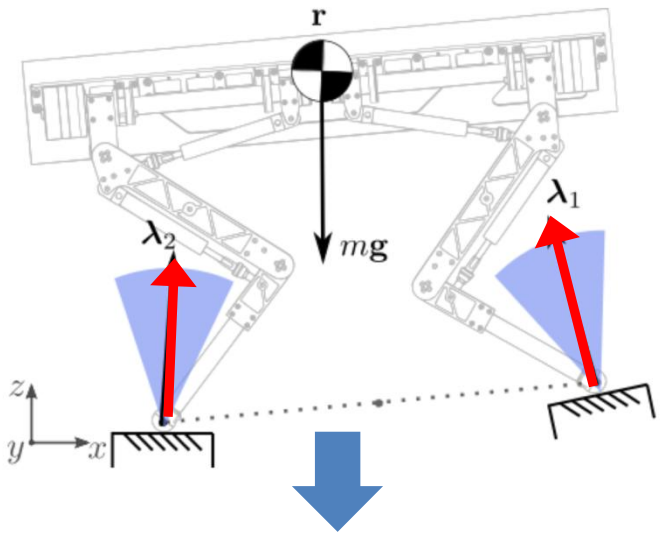
Types of lower dimensional models

LINEAR INVERTED PENDULUM



2D

SINGLE RIGID BODY DYNAMICS



6D

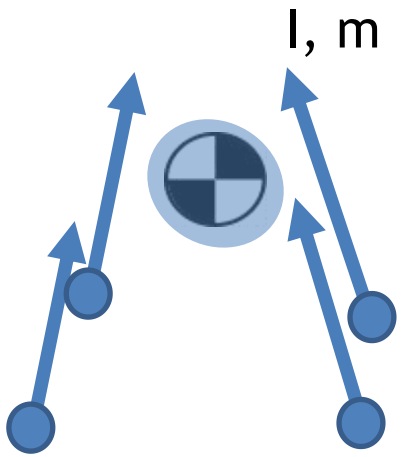
- Models the robot as a single **rigid body** => Captures both the linear and angular dynamics of a robot, allowing generation of 3D motion in space.
- Inputs are **ground reaction forces**, so friction limits are expressable

A

- Neglect the influence of legs dynamics
- having constant inertia: good assumption for quadrupeds where most of the mass is concentrated in the trunk

Simplifying assumptions of single rigid body dynamics

- Consider constant inertia



- Neglect the influence of legs dynamics on the floating base and express equations at CoM

$$\begin{bmatrix} M_b(q) & M_{bj}(q) \\ M_{bj}^T(q) & M_j(q) \end{bmatrix} \begin{bmatrix} \ddot{q}_b \\ \ddot{q}_j \end{bmatrix} + \begin{bmatrix} h_b(q,\dot{q}) \\ h_j(q,\dot{q}) \end{bmatrix} = \begin{bmatrix} 0 \\ \tau \end{bmatrix} + \begin{bmatrix} J_b(q)^T \\ J_j(q)^T \end{bmatrix} f$$

$$m\left(\ddot{x}_{com} + g\right) = \sum_{i=1}^{c} f_i$$

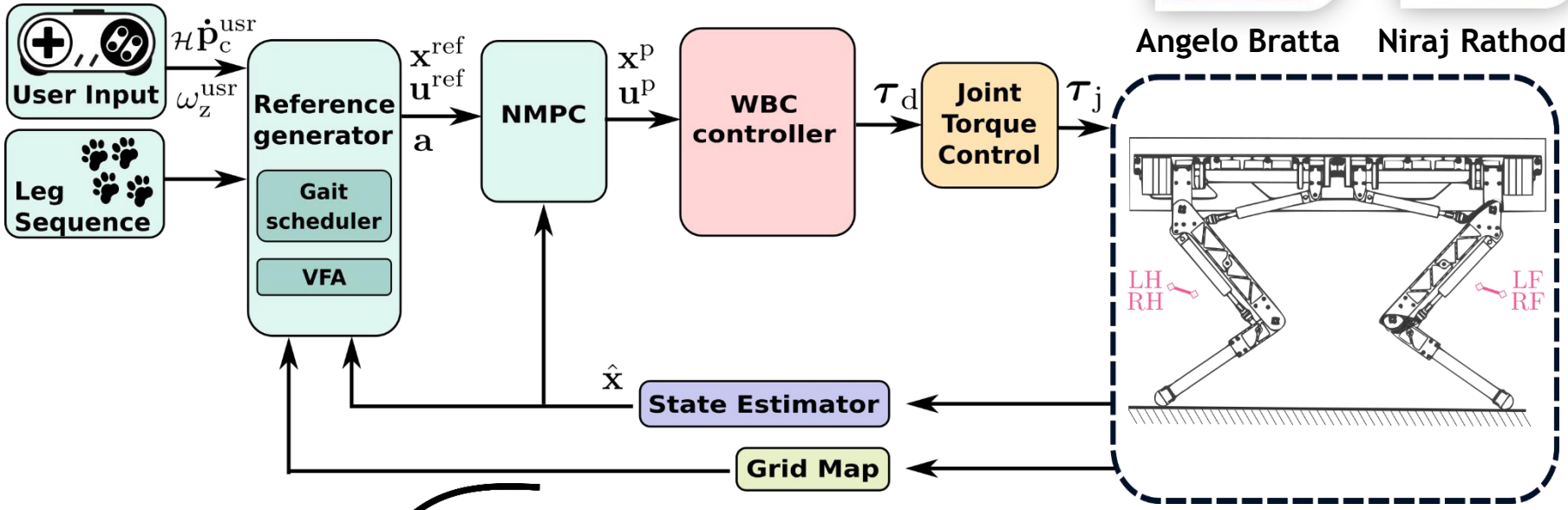
Newton-Euler equations

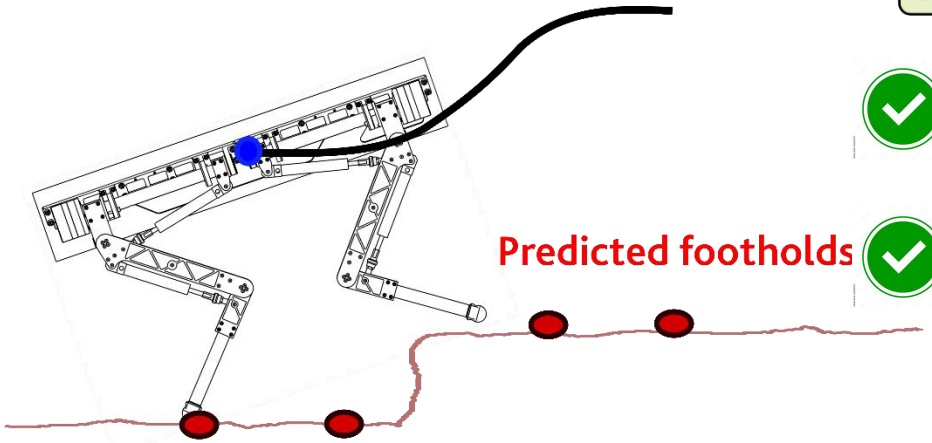
$$I_{com}\dot{\omega}_b \simeq \sum_{i=1}^{c} \left(x_{\mathrm{f},i} - x_{com}\right) \times f_i$$

MPC Planning for rough terrain locomotion

Angelo Bratta

Niraj Rathod





- NMPC running at 25Hz on our robots (50 knots, 2 s horizon, Ts = 40ms)
- Omni-directional walk on **rough** terrain

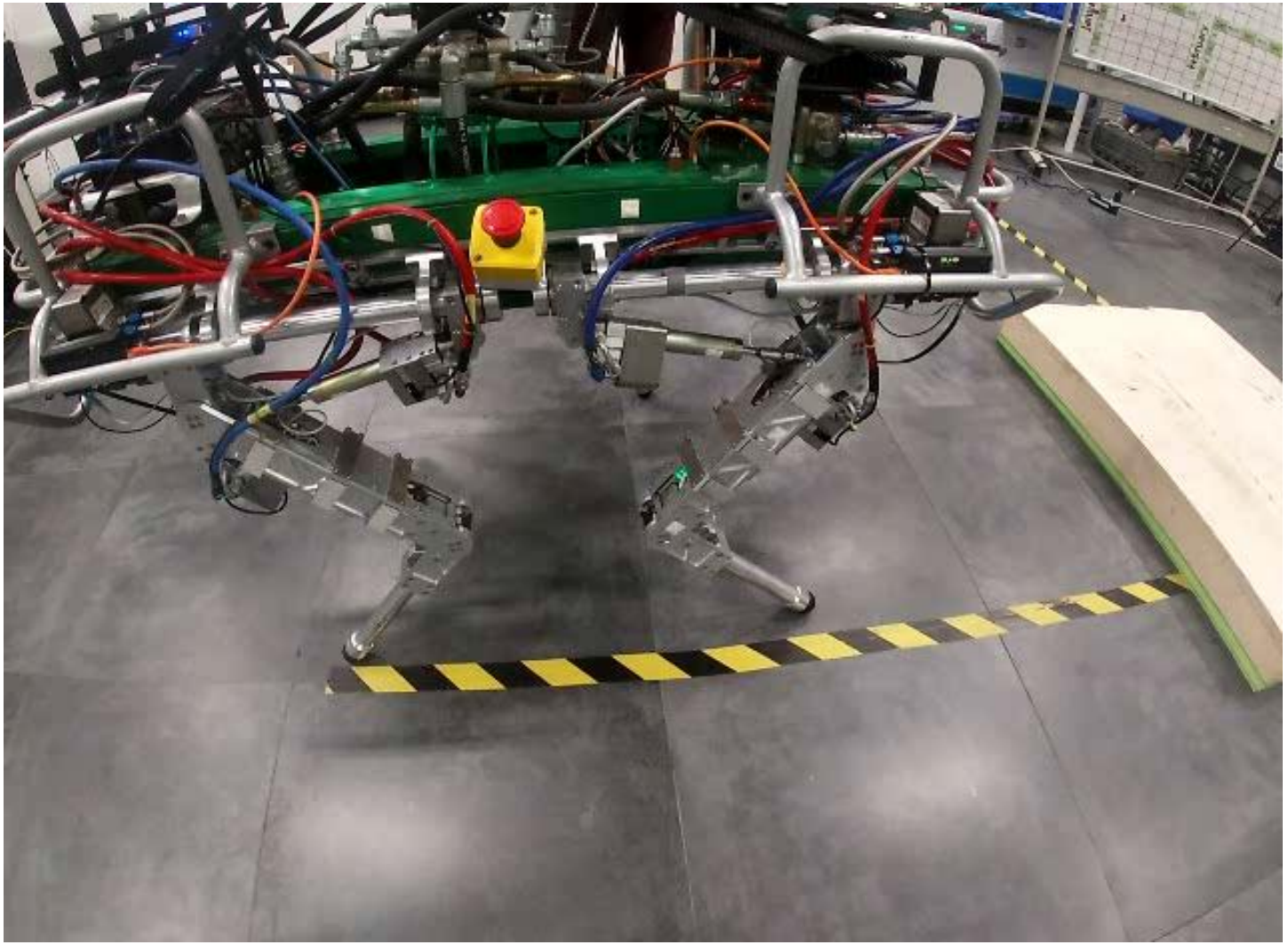
[IEEE Aceess, 2021], 41 cit./3 years

MPC highlights

- Optimization of leg **mobility**  eliminates the need to specify references for the roll, pitch and height of the robot.
- Onboard camera provides a map of the terrain and the normals at the location of the contacts.
- **Online** evaluation of the terrain map for visual foothold adjustment
- Real time iteration implementation (Acados)
- Python interface and Casadi for rapid prototyping, tuning in simulation, generated C-code to perform real experiments. Average computation time NMPC: **5-7 ms**

MPC simulations

MPC experimental results



MPC: quick adaptation to terrain changes (pallet relocation), can cope with state drifts and uncertainties

Future Research: Challenges

Reinforcement Learning/legged robots:
- Omni-directional jumps from a dynamic starting position
- Jump capturability framework

Numerical Optimization:
- Loco-manipulation
- MPC: Contact sequence/timings optimization

Field robotics:
- Slippage aware motion planning for tracked vehicles on slopes
- Autonomous navigation

Robotics applied to Construction Cycle:
- Cable-driven big loads handling with drones

Collaborations

Karl von Elllenrieder
Angelika Peer

Jonas Buchli

Ludovic Righetti

Thiago Boaventura

Leonardo Lanari

Questions?

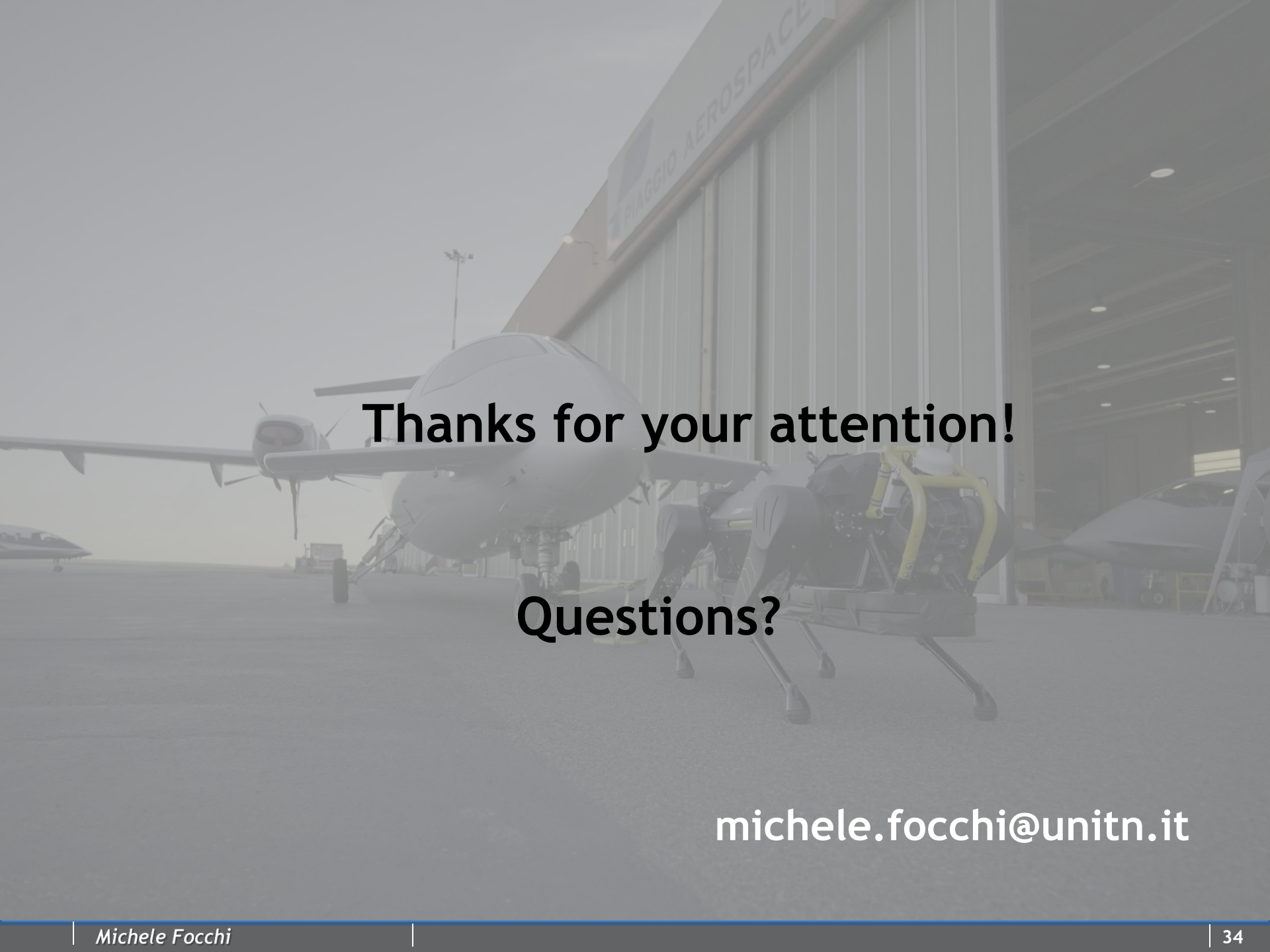
Patrick Wensing

Stéphane Caron

Maurice Fallon

Nicolas
Mansard

Alberto Bemporad
Mario Zanon



Thanks for your attention!

Questions?

michele.focchi@unitn.it