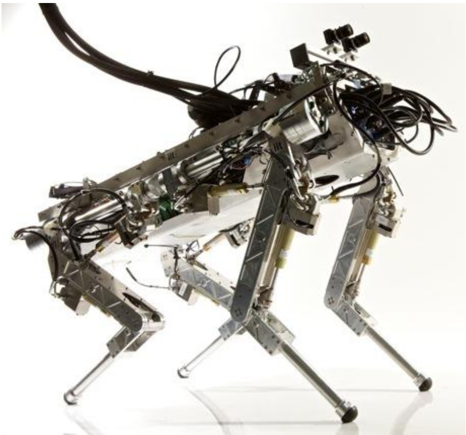
Robust Locomotion Strategies on the HyQ Robot Series



Andreea Rădulescu

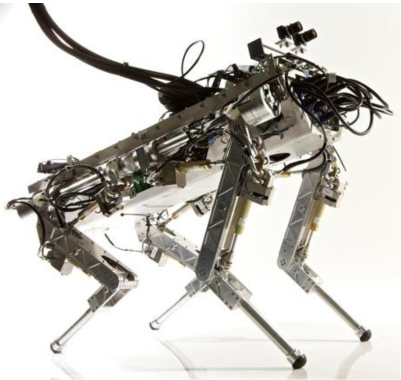
Dynamic Legged Systems Lab
Istituto Italiano di Tecnologia (IIT)

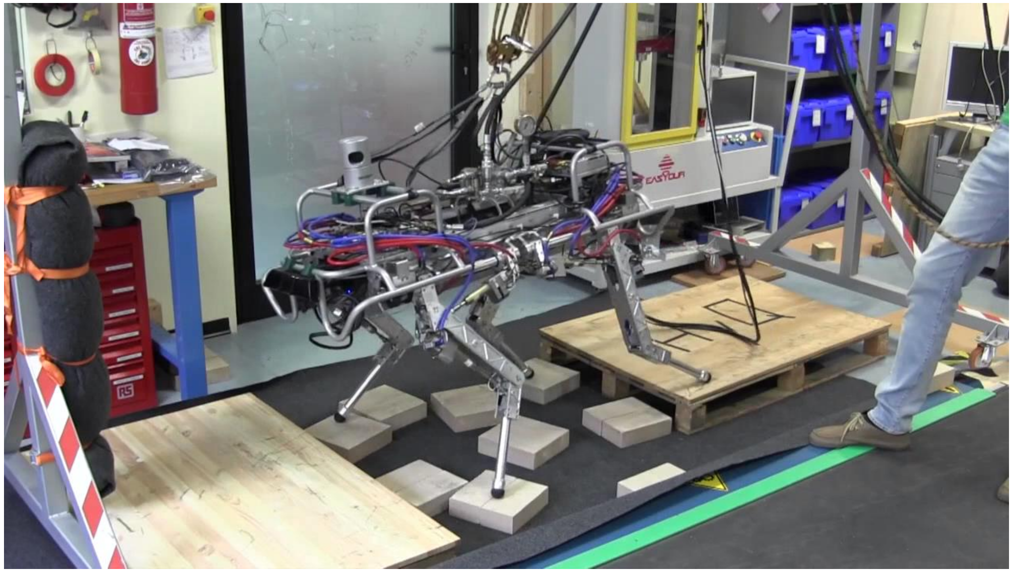
Friday, 25th of May 2018
Dynamic Legged Locomotion in Realistic Terrains

11 years of expertise:

Design and Control/Planning of Dynamic Legged Systems

dls.iit.it





Lab head:
Dr. Claudio Semini

Legged Locomotion in Nature

The Vision: Versatile System

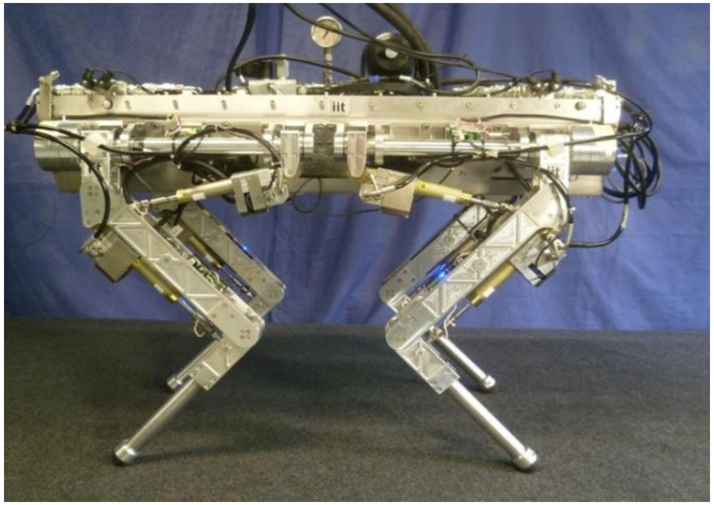
The HyQ Robot Series

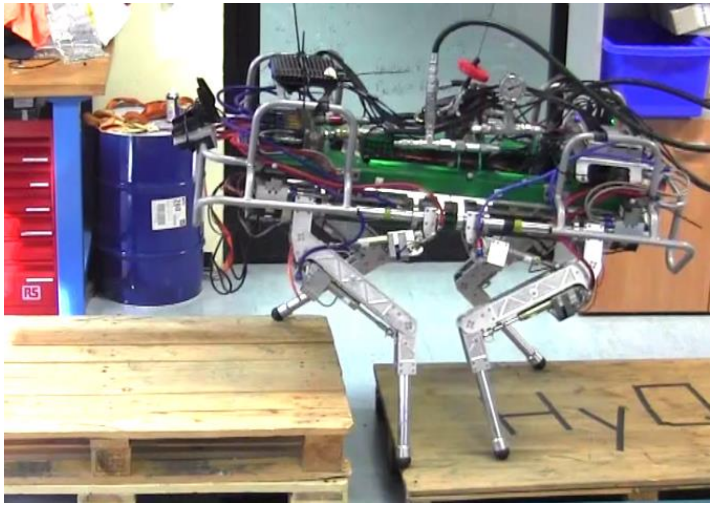
HyQ

HyQ = Hydraulic Quadruped

fully torque-controlled quadruped robot

Property	Value
Dimensions (fully stretched legs)	1.0m x 0.5m x 0.98m (LxWxH)
Weight	80kg (external hydraulics), 110kg (onbard hydraulics)
Active DOF	12; 3 per leg (all hydraulic)
Joint range of motion	120º
Actuators	hydraulic cylinders and rotary vane actuators
Max. Torque	120Nm (Hip ab/add, vane type), 181Nm (Hip f/e+knee, cylinder)
Onboard sensors	joint position + torque, IMU, oil pressure, cameras
Onboard computers	IntensePC i5, real-time Linux
Control frequency	1kHz (position + **torque**)

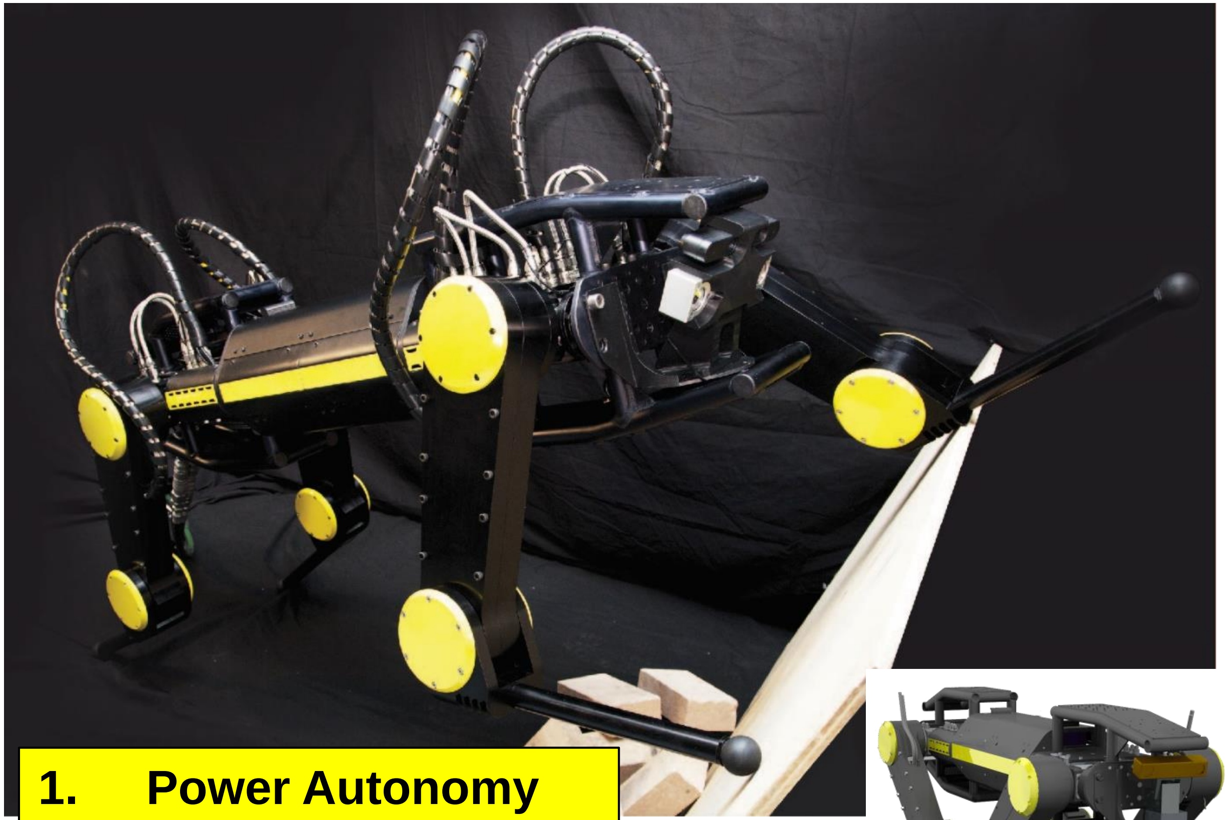




C. Semini et al, JSCE, 2011

HyQ2Max

HyQ2Max robot (2015)



1. Power Autonomy
2. Robustness
3. Reliability

Features

- Same weight as HyQ (80kg)
- Rugged design
- Higher joint torque
- Improved torque output curve
- Larger joint range of motion
- Self-righting capability

Design by Jake Goldsmith (IIT)

C. Semini et al., SICFP, 2015

Locomotion Strategies

Locomotion Strategy and Gait Selection

- Crawl
- Trot
- Non Periodic Movements
- Automatic Gait Discovery

- Reactive
- Vision-enhanced
- Machine Learning (Deep Learning)
- Planned Footholds

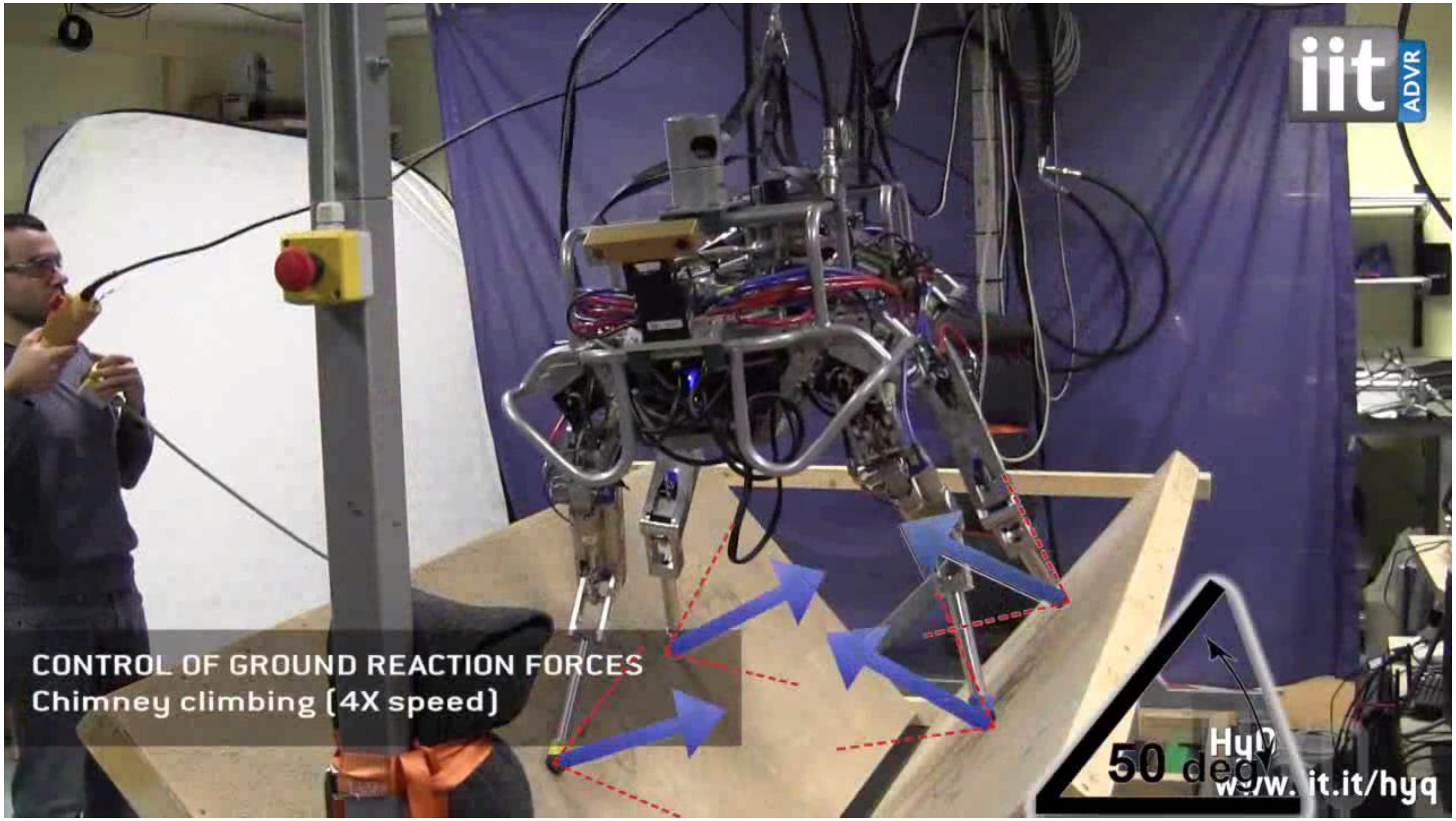
Reactive Approaches

Reactive Crawl

M. Focchi et al. AURO, 2017

Reactive Crawling with optimized GRF

- Chimney Climbing with optimized distribution of joint torques

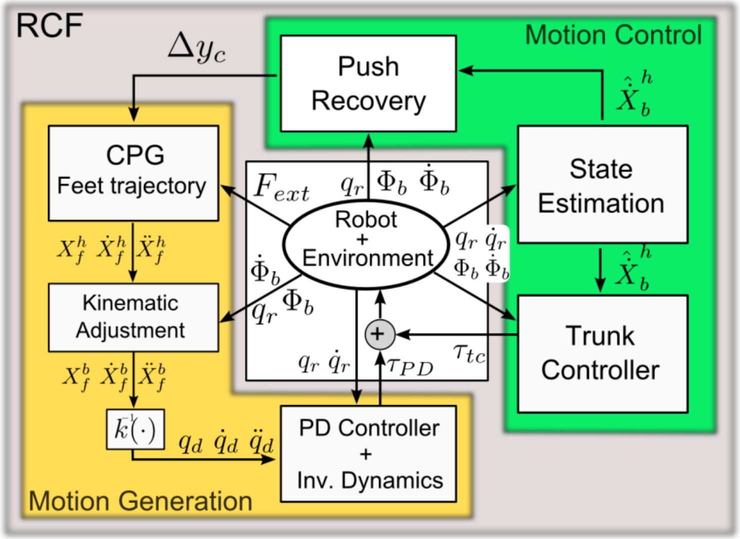


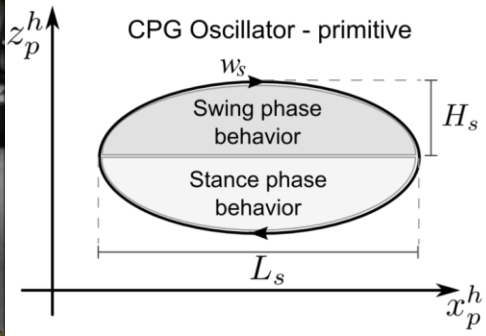
M. Focchi et al. AURO, 2017

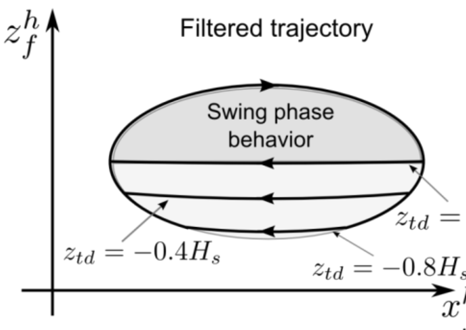
Reactive Controller Framework (RCF)

Reactive Controller Framework

- Omnidirectional trotting controller
- Adaptation to rough terrain
- Balance, Push recovery
- Reduction of impact forces







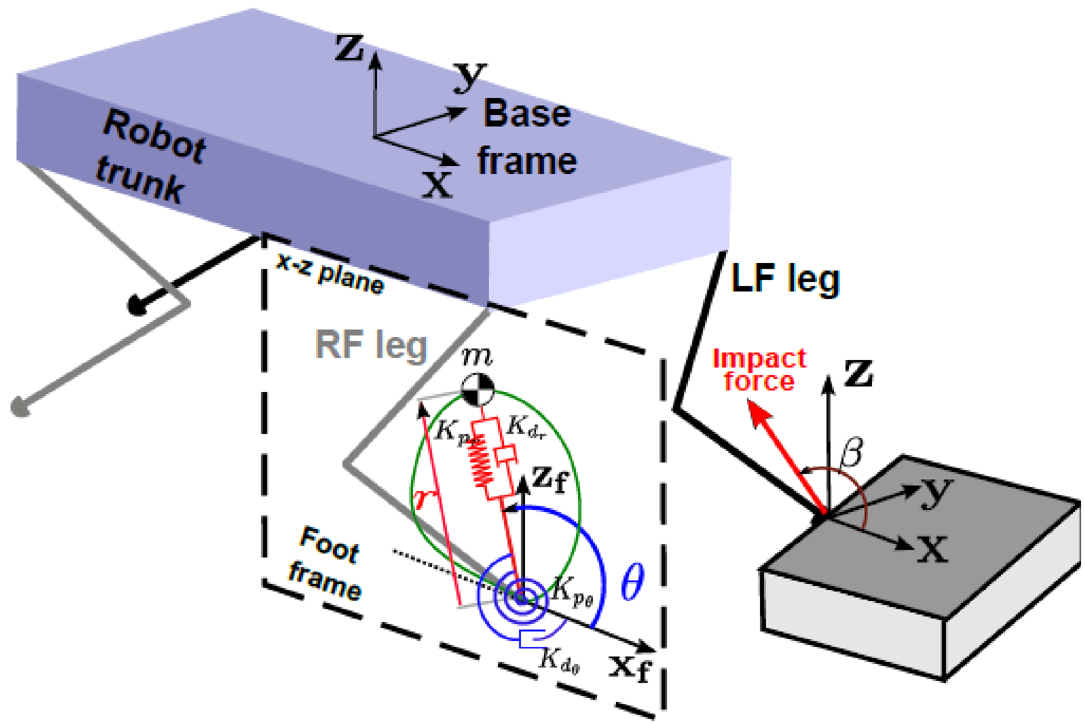
H_s:	step height
L_s:	step length
z_{td}:	step depth

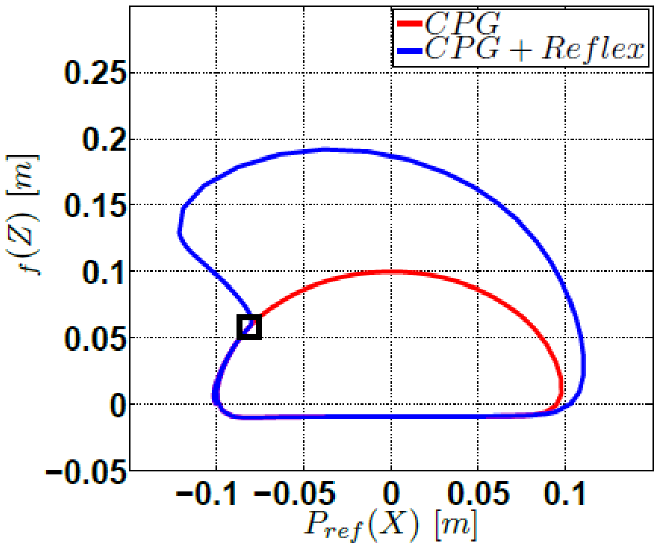
w_s:	angular frequency
$\overline{w}_s$:	average angular frequency

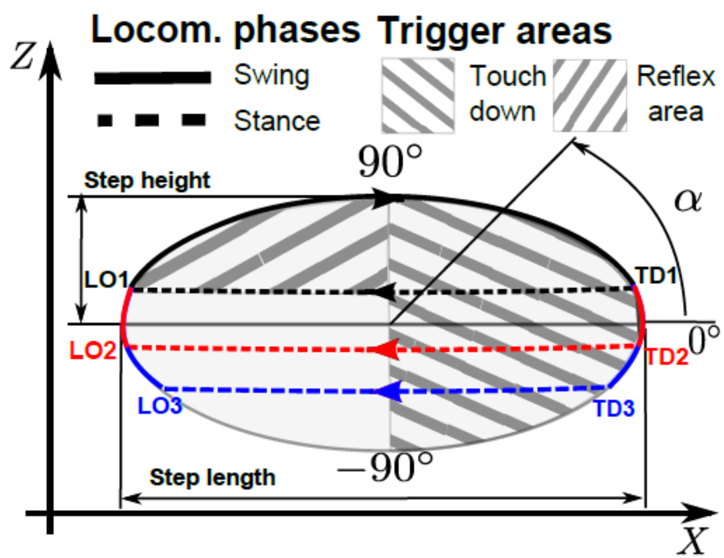
V. Barasuol et al, ICRA, 2013

Adaptive Locomotion – Step Reflex

Local Elevator Reflex



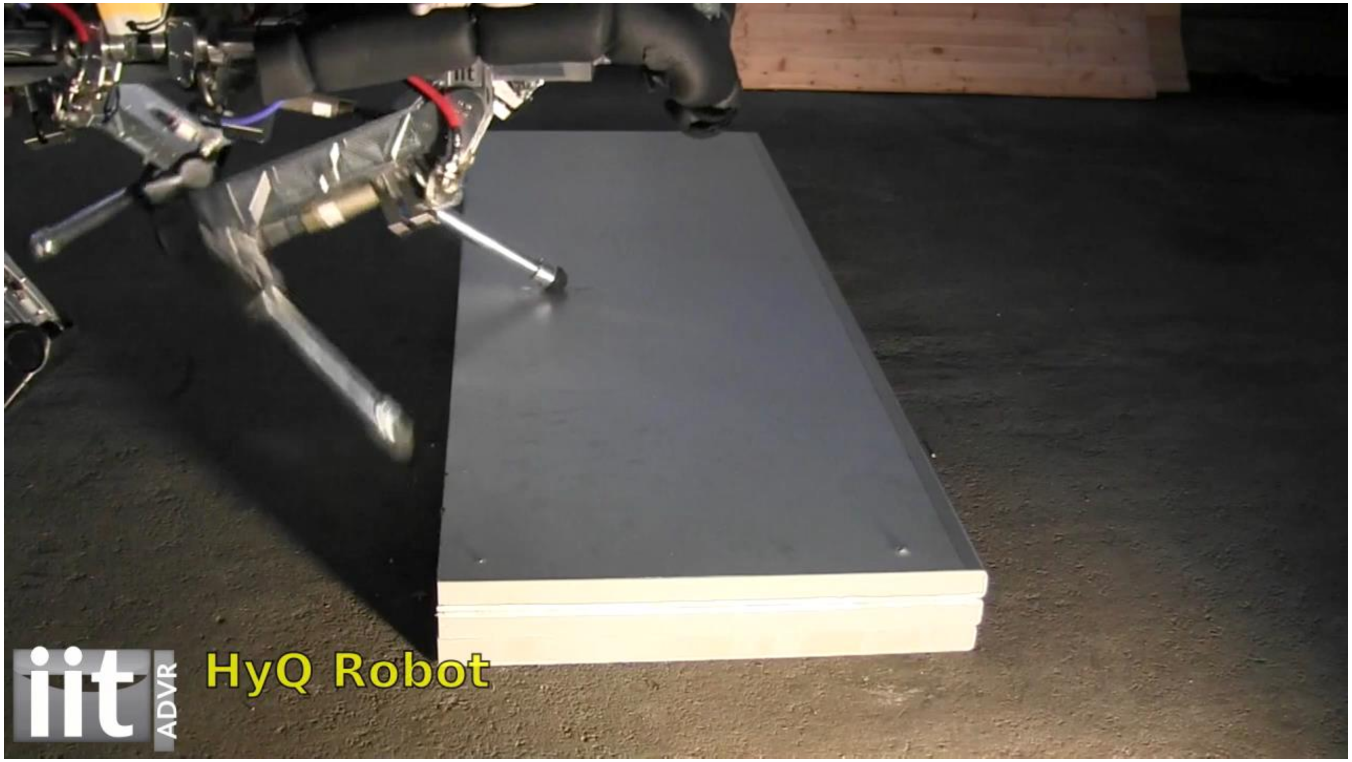




M. Focchi et al, CLAWAR, 2013

Experiments on HyQ

- Elevator step reflex
  with step reflex



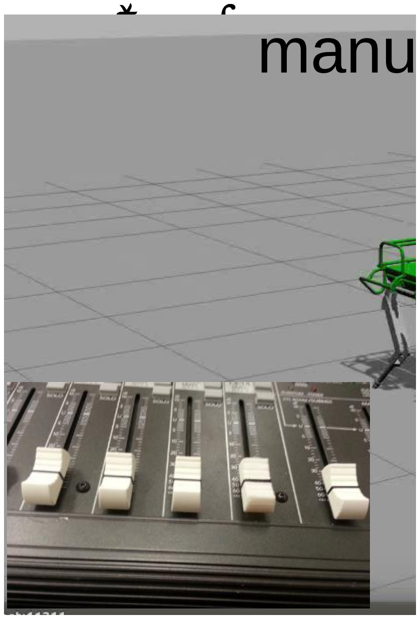
M. Focchi et al, CLAWAR, 2013

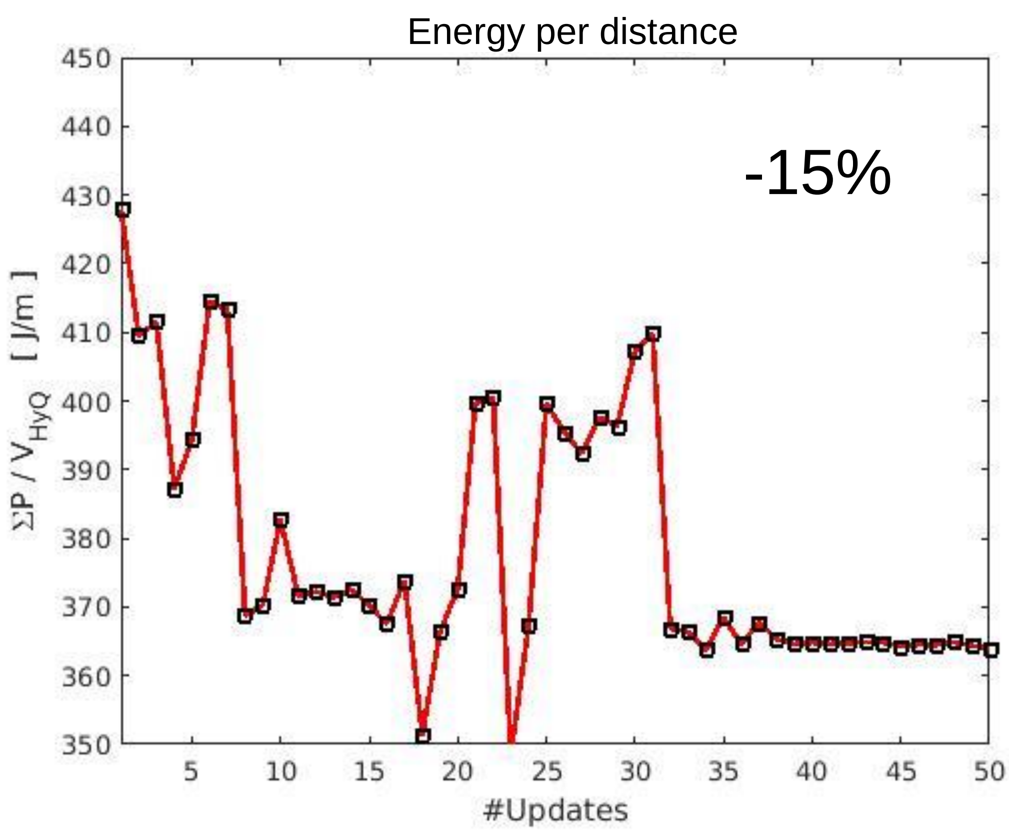
Important in case of:

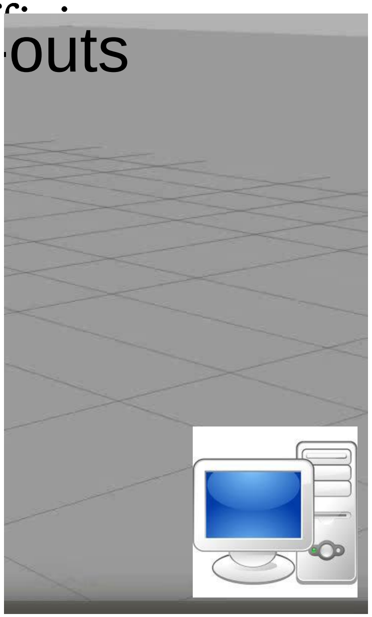
- **No/bad perception due to smoke, vegetation**
- **3D mapping or state estimation error**

RCF + Machine Learning

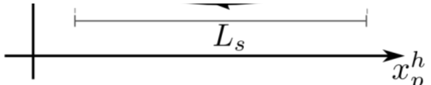
Using PI² we improve the performance* of a trotting gait by learning the gait parameters, impedance profile and the gains of the control architecture.



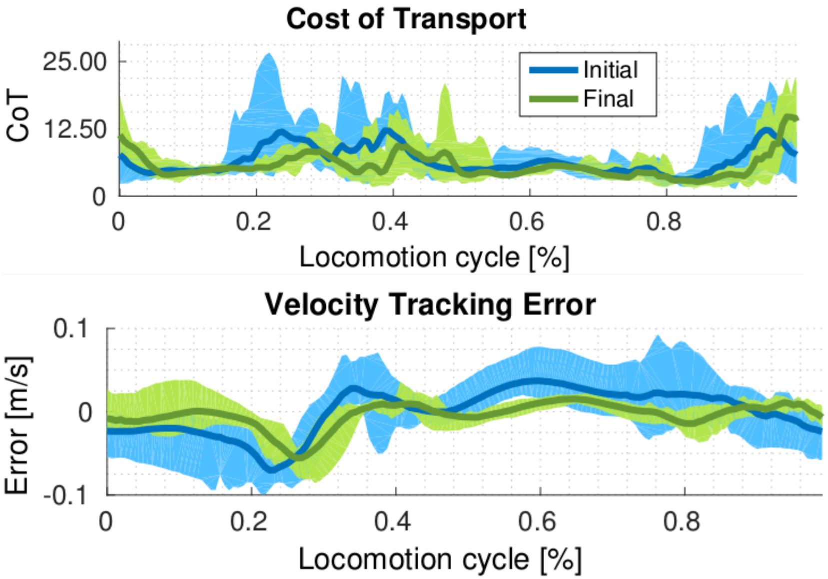




E. Heijmink et al. Humanoids, 2017



RCF + Machine Learning

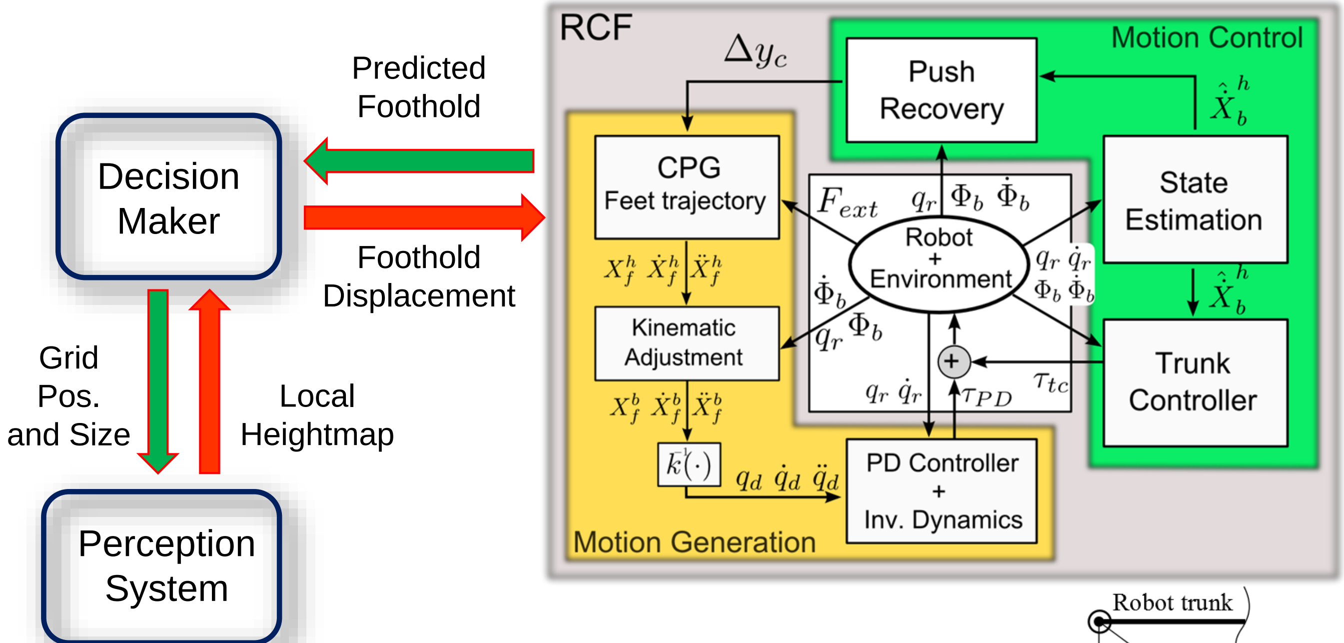


Heijmink et. al, Humanoids 2017

Incorporating Visual Information

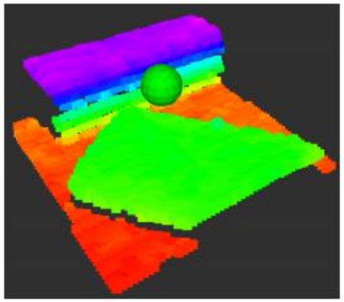
Reactive Controller Framework ++

- Online generated local maps for vision-enhanced reactive locomotion

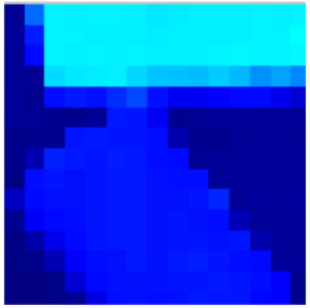


Asus Xtion Pro

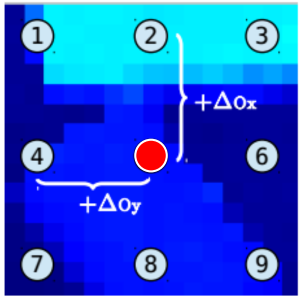
Local 3D Map

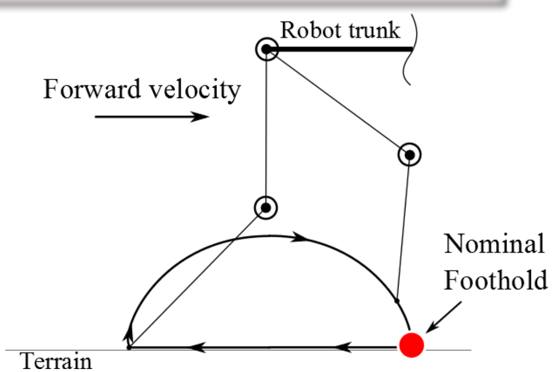


Local Heightmap



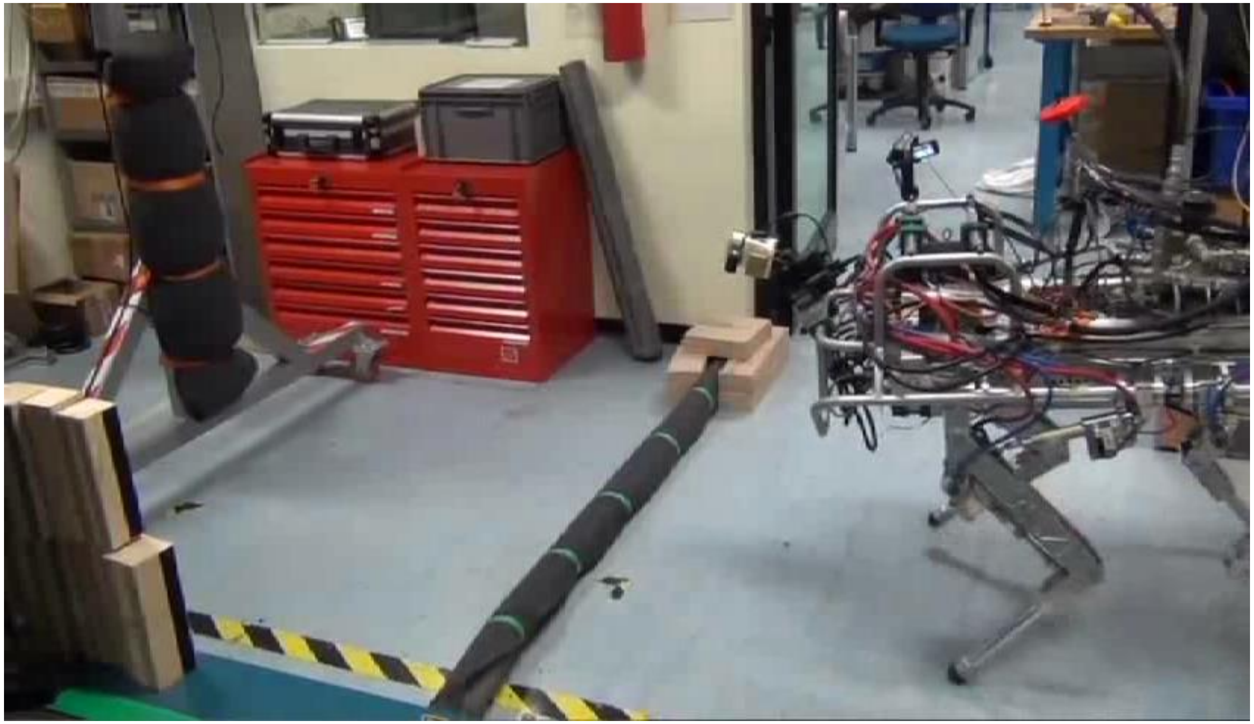
Output: relative position

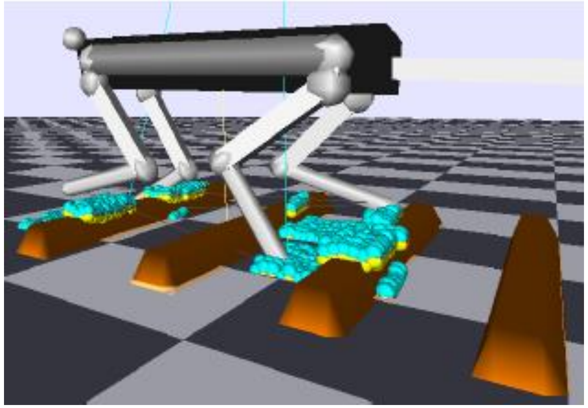




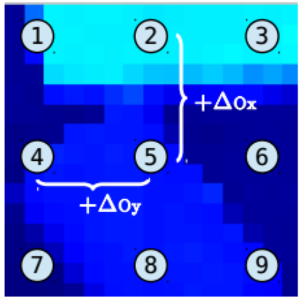
V. Barasuol, M. Camurri et al, IROS, 2015

- Online generated local maps for vision-enhanced reactive locomotion





Output dimension:
9 (3 x 3)



V. Barasuol, M. Camurri et al, IROS, 2015

Vision-enhanced RCF + Deep Learning

Deep Convolutional

Terrain Assessment for

Visual Reactive Footstep

Correction

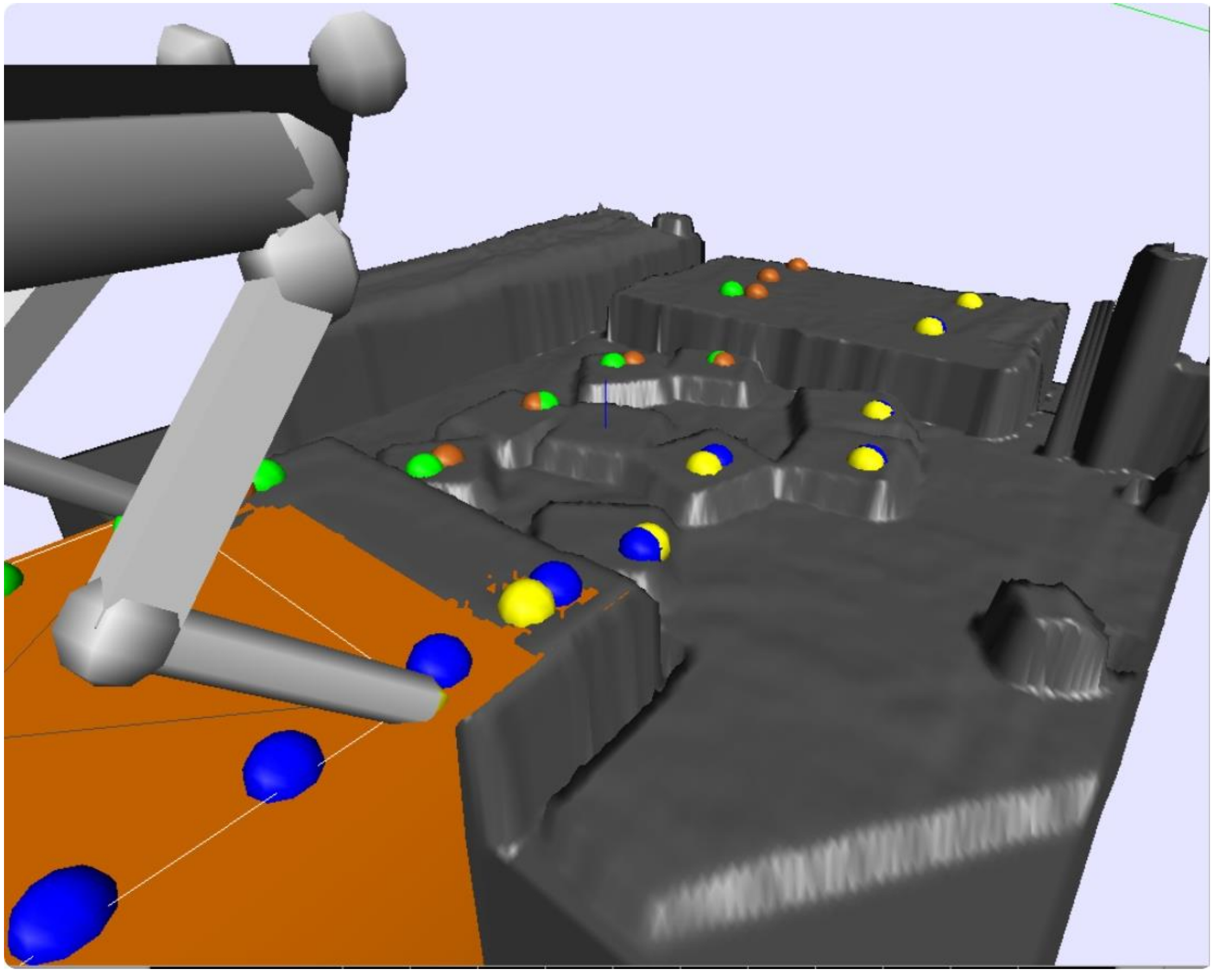
- Real-time dynamic foothold correction strategy using visual feedback
- The feet landing positions are reactively adjusted online
- The foothold selection is given by a CNN (self-supervised terrain classifier trained offline)

Villarreal-Magana et. al, submitted to IROS 2018

Foothold Planning

Foothold planning using maps

- Offline/online generated maps with RGBD sensor for planning of footholds



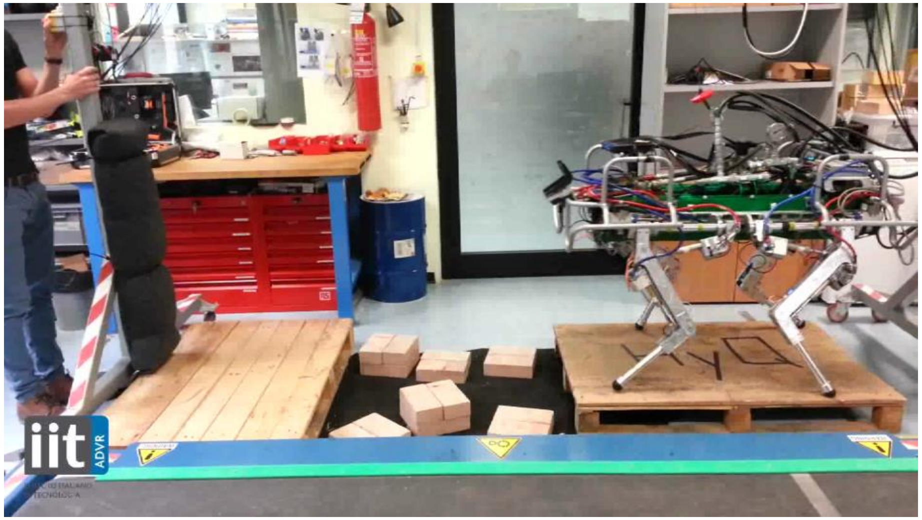
Asus Xtion Pro

Bumblebee

Multisense SL

Crawl with Planned Footholds

- **Coupled planning of robot base trajectory and footholds**



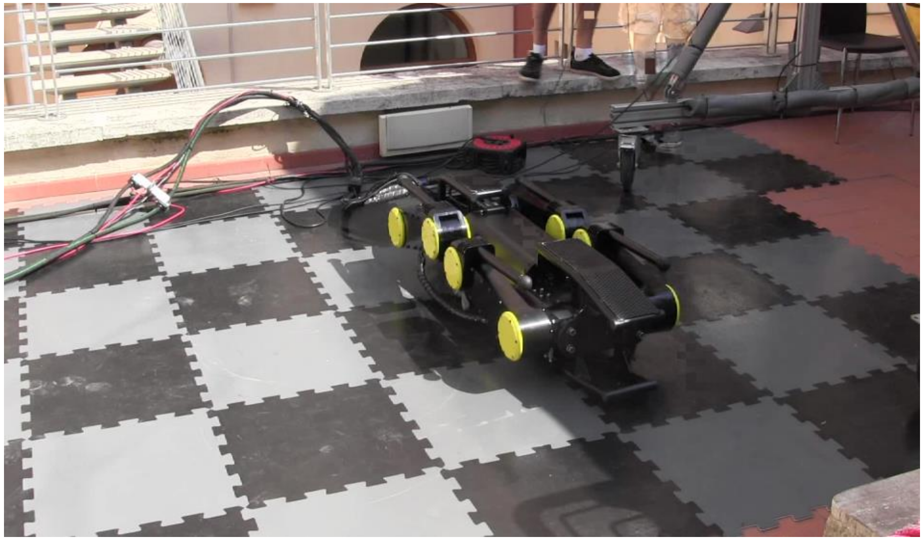
Trial 1

Trial 2

C. Mastalli, et al. ICRA 2017

Non Periodic Movements

HyQ2Max



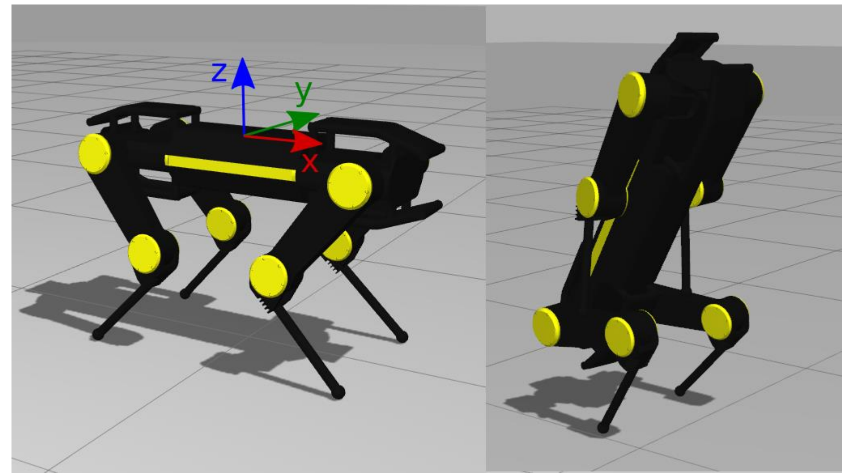
Self-Righting

Finite State Machine

Predefined Poses

HyQ2Max demo at RSS 2015

Whole-body Trajectory Optimisation for Non-periodic Dynamic Motions

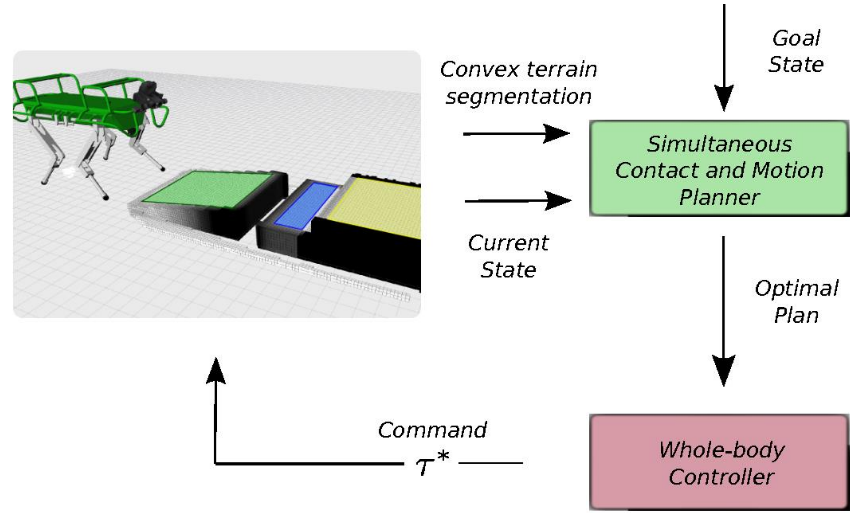


- Whole body optimization methodology for non-periodic dynamic movements
- Trajectory solutions involve multiple contacts, without any predefined feet placement heuristics (e.g., contact points, timing or order of succession)
- Realistic simulation of the hydraulically actuated HyQ2Max quadruped for rearing and posture recovery task

A. Radulescu et. al , ICRA 2017

Automatic Gait Discovery

Robust Multi-Legged Locomotion via Mixed-Integer Convex Optimization



simultaneous optimization of contact locations and motions

formal robustness guarantees through friction cone constraints

automatic gait discovery through mixed-integer constraints

B. Aceituno-Cabezas et. al , ICRA 2018

Conclusions

A combination of reactive and planned motion strategies leading to a robust locomotion performance

Thank you to my wonderful colleagues

Not in the picture:

Yifu Gao

From the left: Michele Focchi, Marco Camurri, Victor Barasuol, Octavio Villarreal, Evelyn D'Elia, Andreea Radulescu, Fabrizio Romanelli, Claudio Semini, Marco Ronchi, Jonathan Brooks, Andrzej Reinke, Romeo Orsolino, Gennaro Raiola, Shamel Fahmi

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- Moog Inc.
- IIT's Advanced Robotics Department

Additional funding through:

Questions?

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