A Compliant Control Architecture for the Hydraulic Quadruped - HyQ

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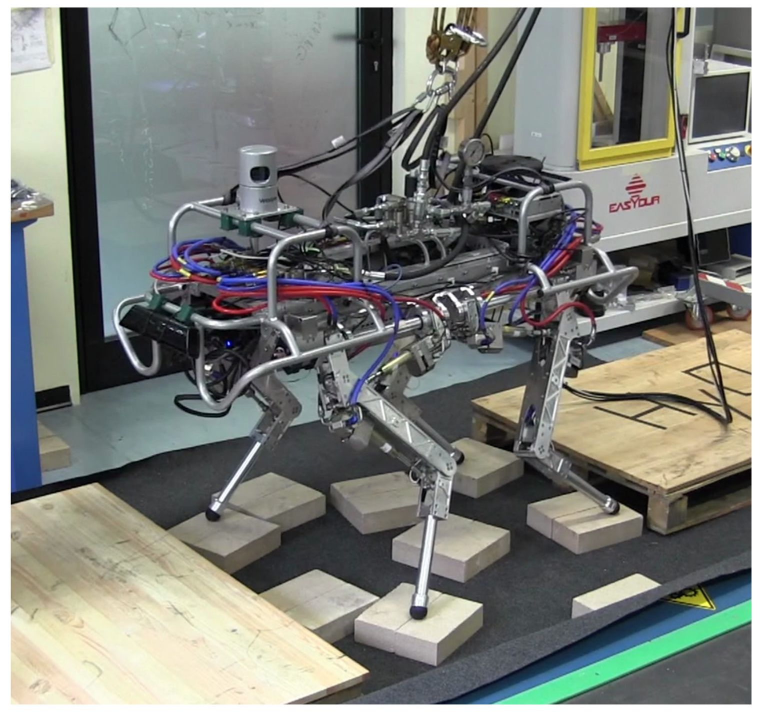
Motivation

- A **locomotion** controller for
  - Dynamic **Trotting**
  - Static **Crawling**
- Uses ***proprioceptive*** information
  - Joint encoders, force sensors, IMU
- **Robust** against
  - Pushes, **modeling/perception** inaccuracies
  - **Dynamically** changing environments

[*]



Hydraulic Quadruped - HyQ

- Designed and built in-house
- 12 DoFs [1]
  - 4 **rotational** actuators
  - 8 **linear** actuators
  - ***Fully torque controlled***
  - No springs attached

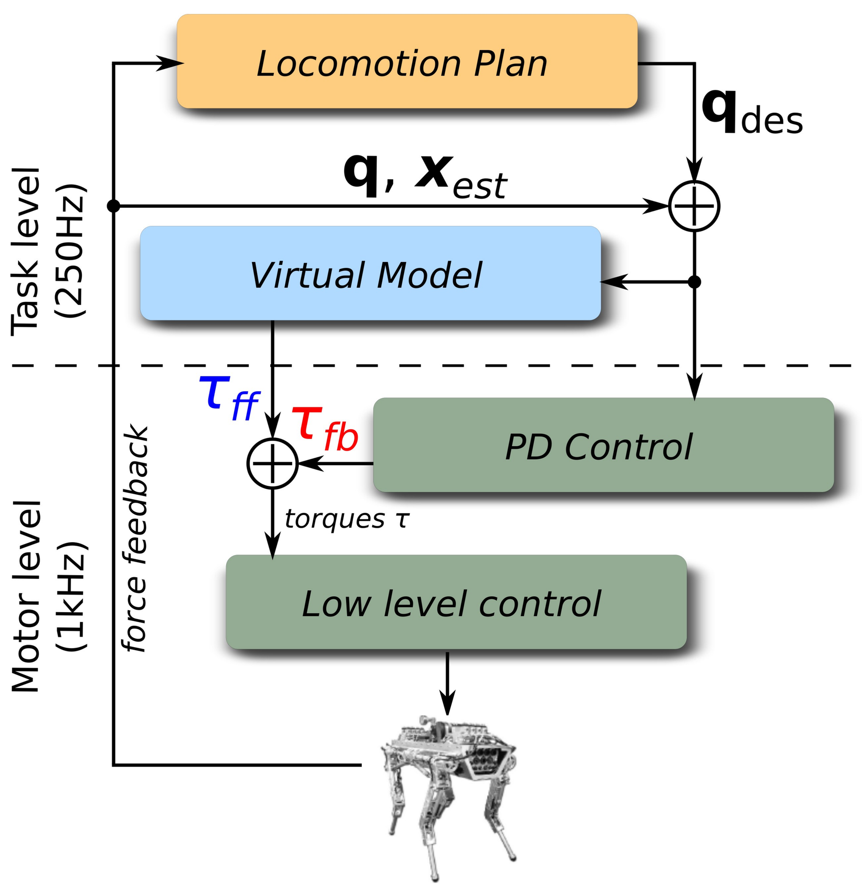
Controller Overview

A combination of

- **Trajectory Generation**
  - Low-gain *PD*

    (**feedback** - τ_{fb})
- **Trunk Stabilization**
  - *Virtual Model*

    (**feedforward** -τ_{ff})



References
[1] C. Semini, N. G. Tsagarakis, E. Guglielmino, M. Focchi, F. Cannella, and D. G. Caldwell, “Design of HyQ – a hydraulically and electrically actuated quadruped robot,” Journal of Systems and Control Engineering, 2011.
[2] M. H. Raibert, Legged robots that balance. Cambridge, MA, USA: The MIT Press, 1986.
[3] J. Pratt, C. M. Chew, A. Torres, P. Dilworth, and G. Pratt, “Virtual model control: An intuitive approach for bipedal locomotion,” The International Journal of Robotics Research, 2001.
[4] G. M. Nelson, R. D. Quinn, "Posture control of a cockroach-like robot," Control Systems, IEEE , vol.19, no.2, pp.9,14, Apr 1999.
[*] http://www.editions-tredaniel.com/que-pense-votre-chat-p-3356.html

Trajectory Generation

Compute **foot-fall targets** according to

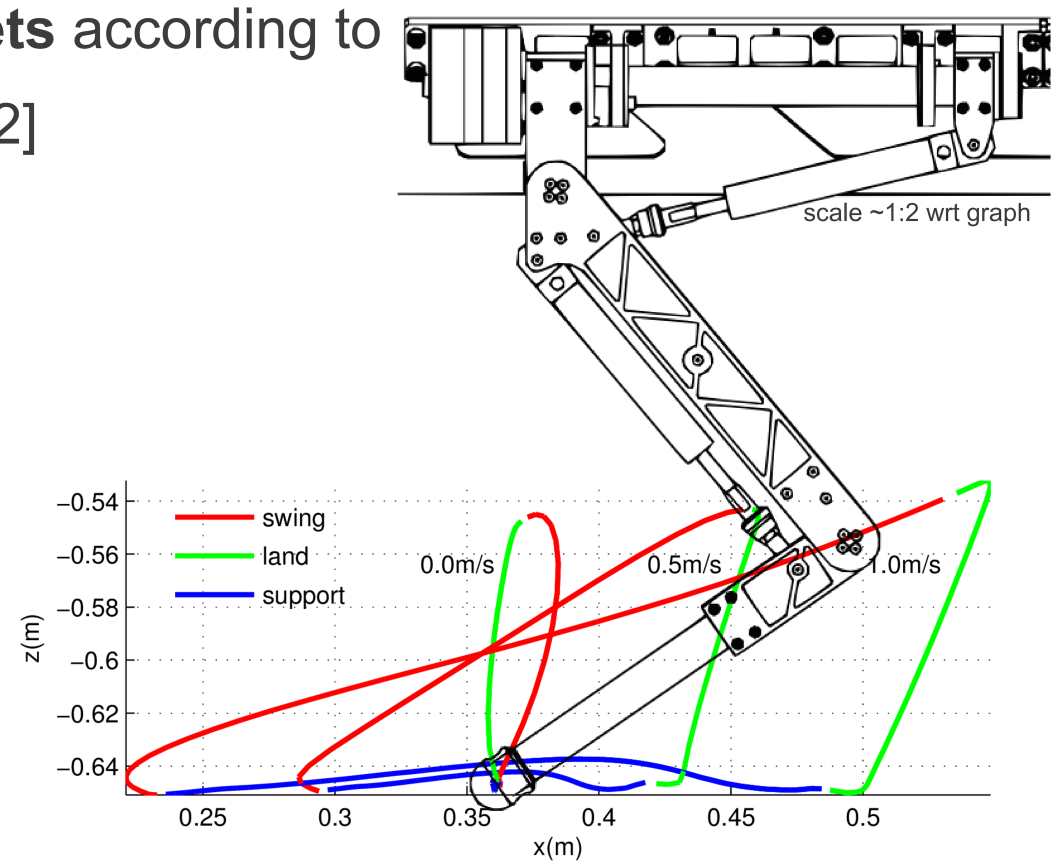
- desired velocity [2]
- stance duration

Swing legs

- swing to target
- feet landing

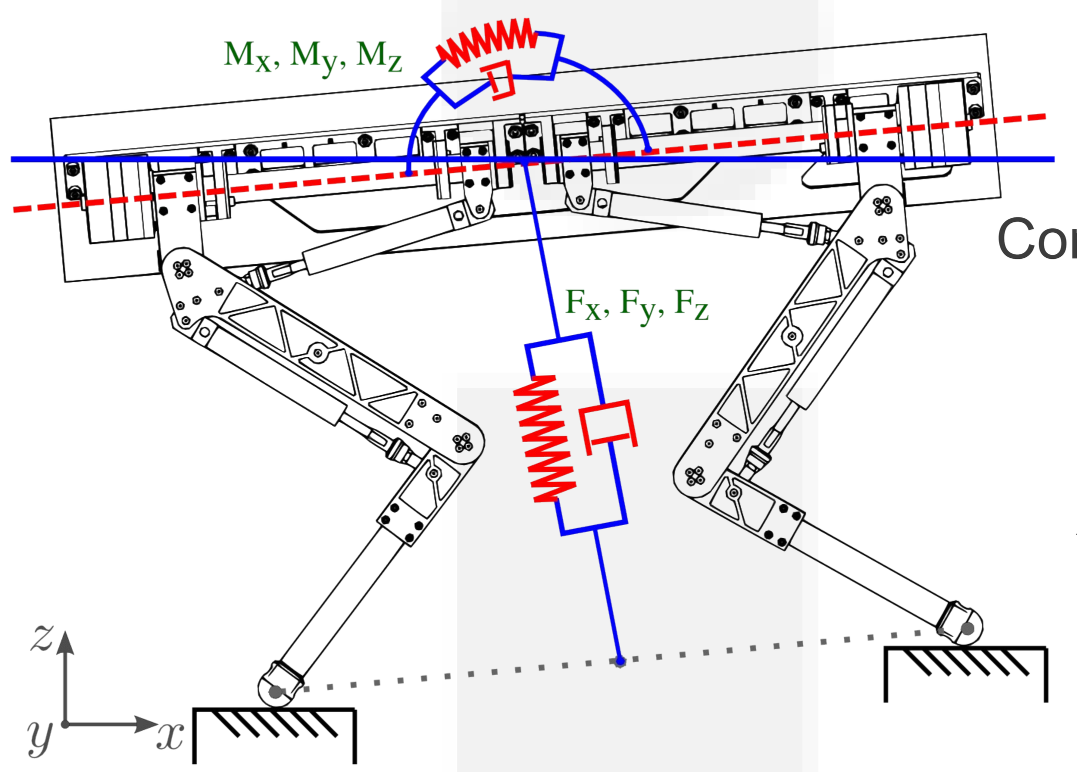
Stance legs

- constant velocity
- support



Virtual Model Formulation

Computes a ***feedforward*** torque commands according to the *reference* state and the *estimated* state of the trunk [3, 4].



Compute *generalized* **forces** and **moments**

$$\boldsymbol{F} \quad \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} \qquad \boldsymbol{M} \quad \begin{bmatrix} M_x \\ M_y \\ M_z \end{bmatrix}$$

Distribute according to the **contact** conditions

$$\begin{bmatrix} I & \dots & I \\ [x_{leg_1}]_\times & \dots & [x_{leg_n}]_\times \end{bmatrix} \begin{bmatrix} F_{leg_1} \\ \vdots \\ F_{leg_n} \end{bmatrix} = \begin{bmatrix} \boldsymbol{F} \\ \boldsymbol{M} \end{bmatrix}$$

Map forces to torques

$$\tau_{ff} = \begin{bmatrix} J_{leg_1} & \dots & 0 \\ 0 & \dots & J_{leg_n} \end{bmatrix}^T \begin{bmatrix} F_{leg_1} \\ \vdots \\ F_{leg_n} \end{bmatrix}$$

Results

Trot

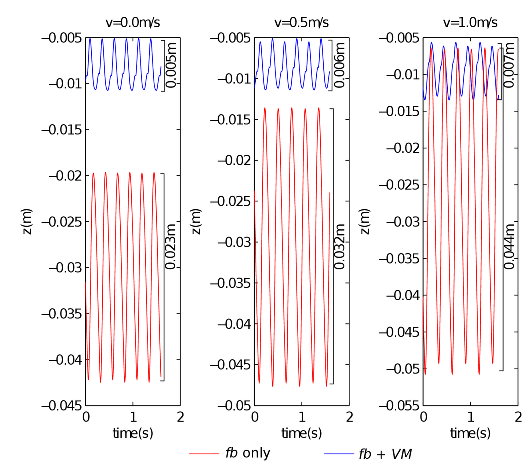
- Decrease in trunk oscillations
- Accurate stance control

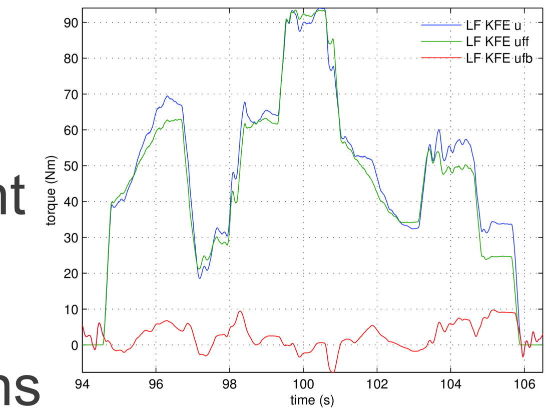
Crawl

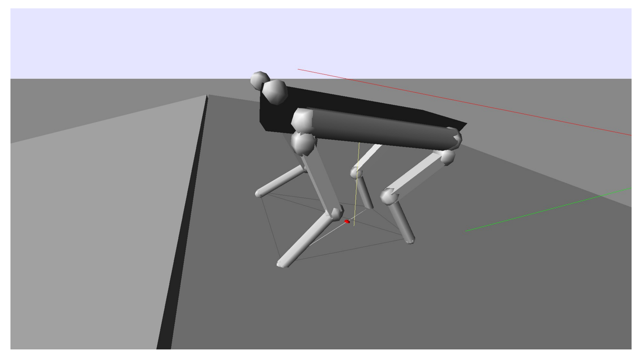
- The behavior fails without the *VM*
- Significant decrease in *PD* gains

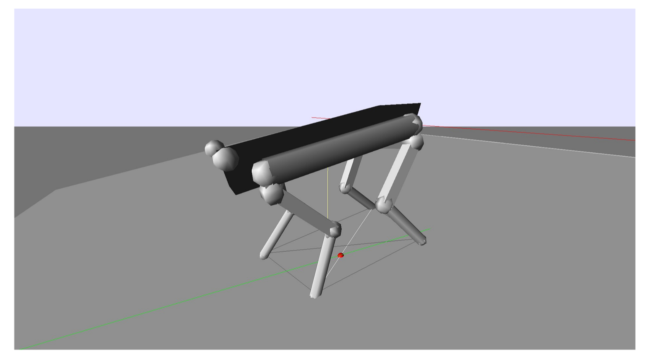
Overall

- Smooth interaction with environment
- Fast stabilization of the trunk
- Minimization of unwanted oscillations



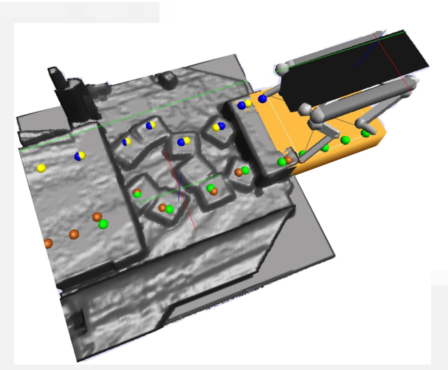


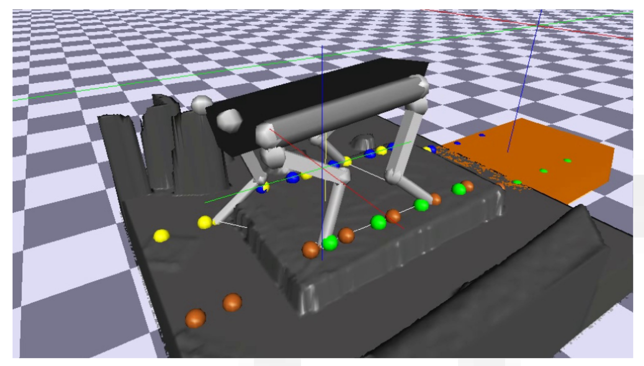

(a) Trot uphill


(b) Trot downhill

± 0.3 *rad*

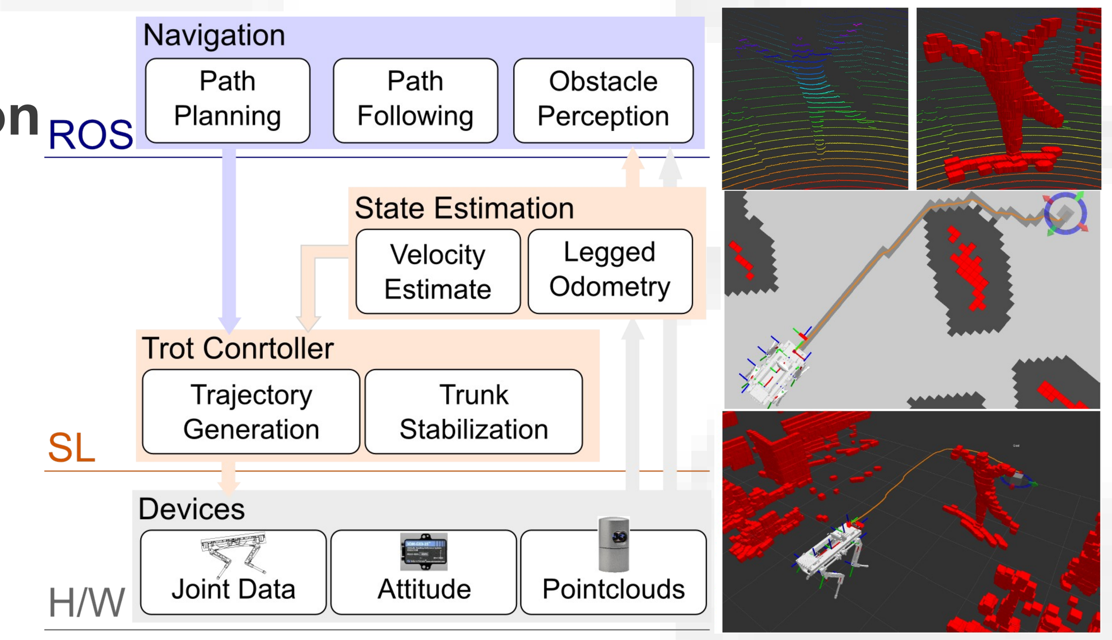
± 0.15 *m*


(c) Irregular terrain


(d) Step on platform

Currently

- Obstacle **perception**
  - *Pointcloud* data
  - Representations
- **Path planning**
  - **Footholds**
  - Navigation



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