On Highly Dynamic Behaviors of Quadrupedal Robots

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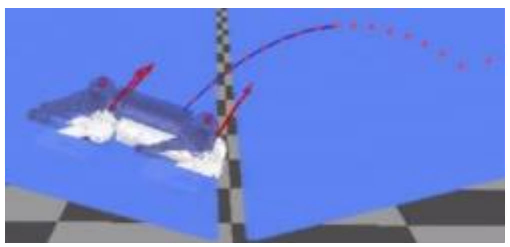
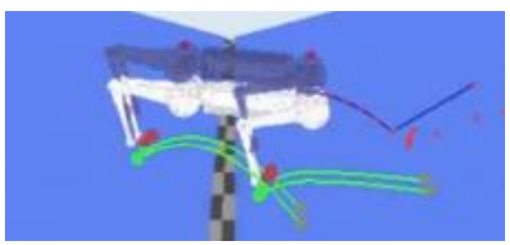
Introduction

One of the biggest challenges in robotics is to perform jumps or running using online optimization. In this work we present an approach to deal with those tasks, exploiting the limits of what the world allows the robot to do from the point of view of control.

Jumps on sloped terrain

The present approach produces *dynamically feasible* trajectories for the CoM position and its angular momentum, and *quasi-dynamically feasible* trajectories for the orientation with a quadratic error.





Control Approach

We use the Centroidal Dynamics model affected by the ground forces (control input) enhanced with the orientation of the robot in quaternion form. The angular momentum is taken around the world coordinate system.

$$\begin{bmatrix} \ddot{\boldsymbol{r}} = \frac{1}{m}\sum \boldsymbol{f}_i + \boldsymbol{g} \\ \dot{\boldsymbol{L}}_2 = \sum \boldsymbol{r}_{pi} \times \boldsymbol{f}_i + m\boldsymbol{r} \times \boldsymbol{g} \\ \dot{\boldsymbol{q}}_r = \boldsymbol{Q}(\boldsymbol{q}_r)\boldsymbol{I}^{-1}(\boldsymbol{q}_r)(\boldsymbol{L}_2 - m\boldsymbol{r} \times \dot{\boldsymbol{r}}) \end{bmatrix}$$

We perform successive QP optimizations over the time-varying linearization of the system.

$$\mathbb{P}_k : \min_{x,u} \int_0^{t_f} \|\mathbf{x}^*_{k-1} - \mathbf{x}\|_{\mathbf{L}} + \|\mathbf{u}\|_{\mathbf{K}} dt$$

$$\text{s.t. } \dot{\mathbf{x}} = A_{k-1}(t)\mathbf{x} + B_{k-1}(t)\mathbf{u} + C_{k-1}(t)$$

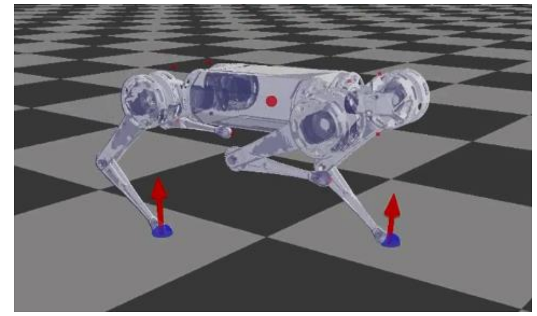
$$\boldsymbol{W}_{\boldsymbol{ROT}}(t)\mathbf{u} \le \mathbf{b}(\mathrm{t})$$

Where $\boldsymbol{W}_{\boldsymbol{ROT}}$ and $\mathbf{b}$ encodes the friction restriction in the ground forces. The resultant optimized trajectory is:

$$\mathbf{x}^*_{\mathrm{k}}(t) = \underset{\mathbf{x}}{\operatorname{argmin}}\, \mathbb{P}_k$$

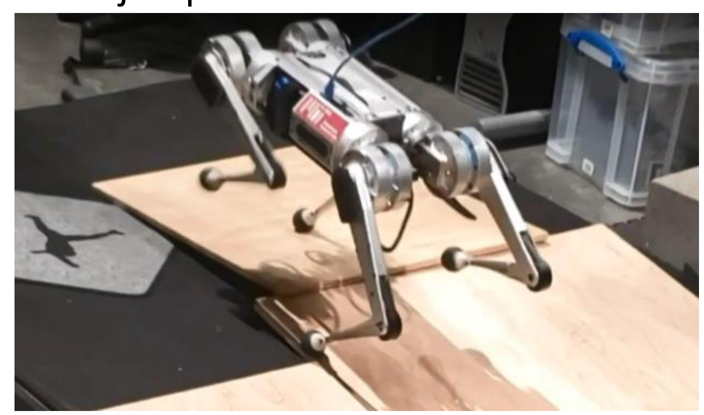
Underactuated tasks

Our approach is able to balance in two legs. In order to compensate for modeling errors, the reference for the CoM position (x-y) is an integral of the orientation errors (pitch-roll).



Experimental test

Walking on sloped terrain has been implemented so far with the present configuration. We aim to perform online-optimized jumps in the real robot.



References

[1] J. Di Carlo, P. Wensing, B. Katz, G. Bledt, and S. Kim. "Dynamic Locomotion in the MIT Cheetah 3 Through Convex Model-Predictive Control", in Intelligent Robots and Systems (IROS), 2018 IEEE-RAS 18th International Conference on, 2018

[2] H. Dai and R. Tedrake. "Planning robust walking motion on uneven terrain via convex optimization", in Humanoid Robots (Humanoids), 2016 IEEE-RAS 16th International Conference on, 2016

[3] G. Garcia, R. Griffin, and J. Pratt "Convex Optimization of the Full Centroidal Dynamics for Planning in Multi-Contact Scenarios," available online at ResearchGate Preprint, Dec 2019

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