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AMBER LAB Caltech www-bipedalrobotics-com

RSL Robotic Systems Lab

Planar Bipedal Locomotion with Nonlinear Model Predictive Control: Online Gait Generation using Whole-Body Dynamics

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Contribution

Whole-Body Nonlinear MPC

Reduced computational cost via HZD Reference & Terminal

Experimental validation on planar biped AMBER-3M

MPC Formulation – Reparametrized Whole-Body Dynamics

Exclude inverse dynamics from MPC prediciton

- $x = (q_b, q_j, \dot{q}_b, \dot{q}_j)^T$
- $u = (\lambda_c, \ddot{q}_j)$
- $\dot{x} = (\dot{q}_b, \dot{q}_j, \ddot{q}_b, \ddot{q}_j)^T$

$$\ddot{q}_b = D_{bb}{}^{-1}(-D_{bj}\ddot{q}_j - C_b(q,\dot{q})\dot{q} - G_b(q) + J_{cb}(q)\lambda_c)$$

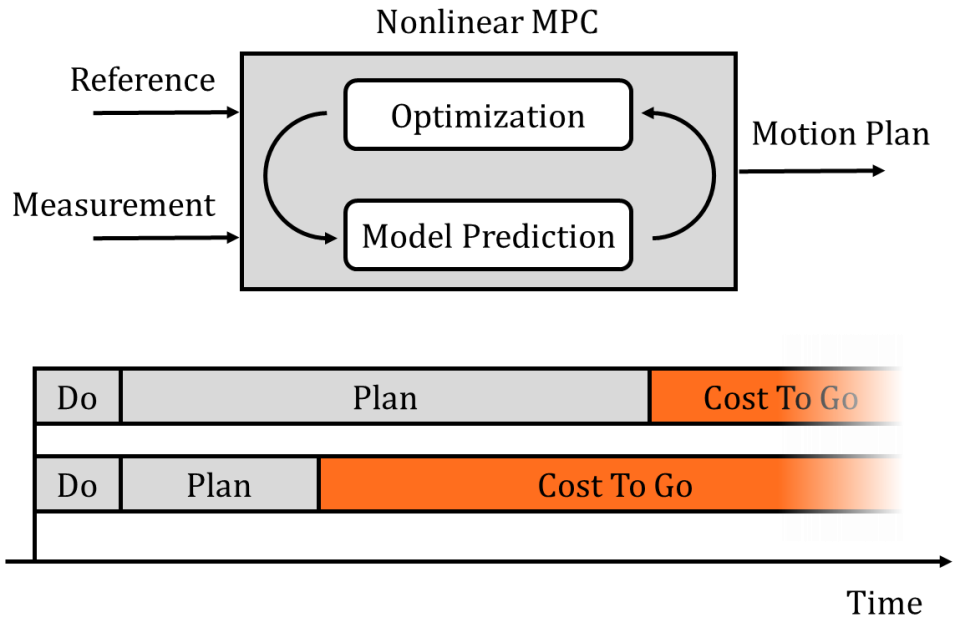
→ **Focus computation on unactuated DoF**

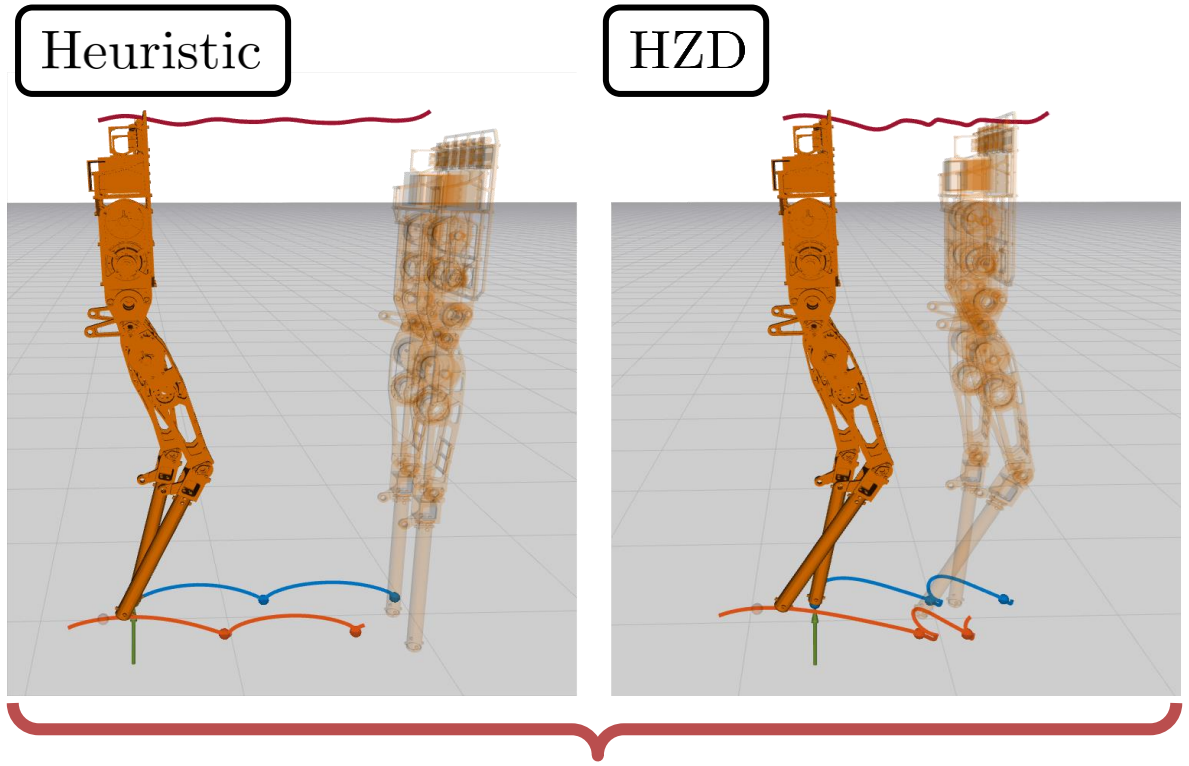
Recover torques via inverse dynamics

$$\tau = J_c^T\lambda_c - D(q)\ddot{q} - C(q,\dot{q})\dot{q} - G(q)$$

→ **Whole-Body nonlinear dynamics/constraints**

Reduce Computational Cost via Horizon Shortening

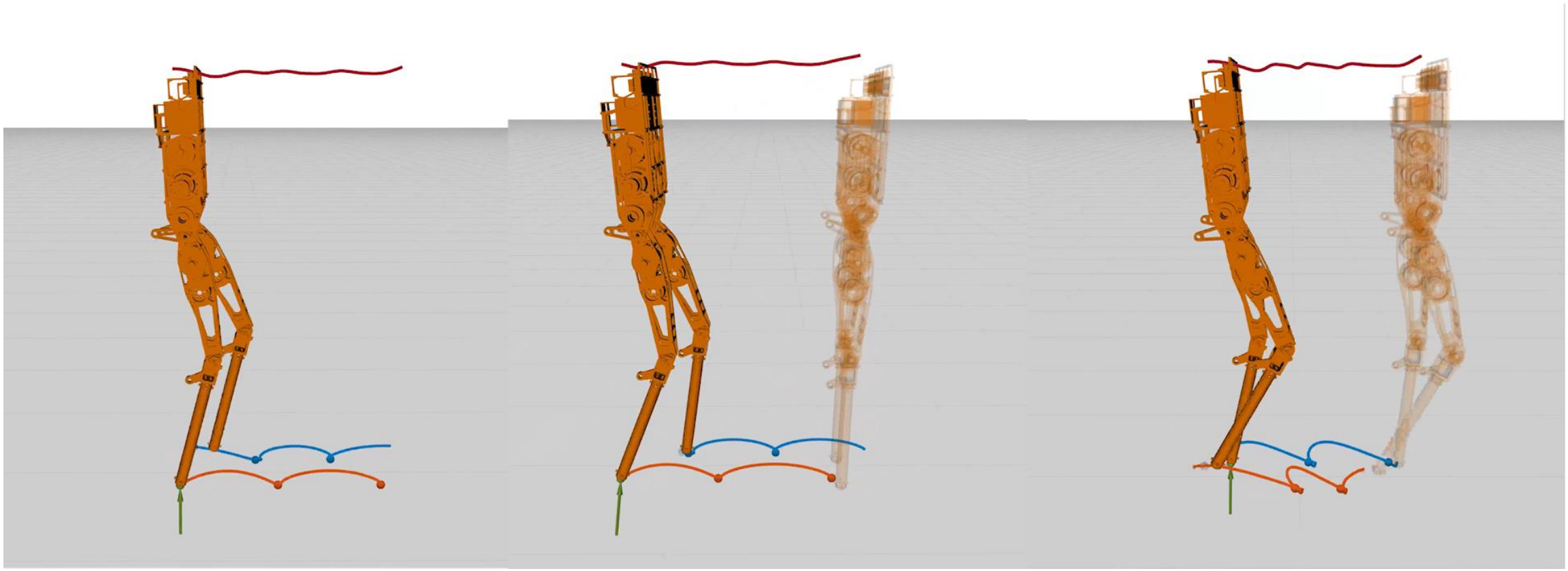




$$\underset{\mathbf{u}(\cdot)}{\text{minimize}} \qquad \phi(\mathbf{x}(t_H)) + \int_0^{t_H} l(\mathbf{x}(t), \mathbf{u}(t), t)\mathrm{d}t$$

MPC Terminal Cost Visualization 2s Horizon

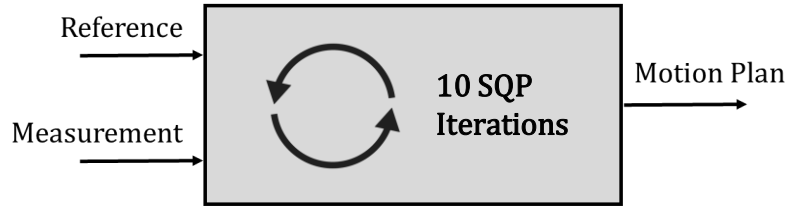
No Terminal | Heuristic Terminal | HZD Terminal

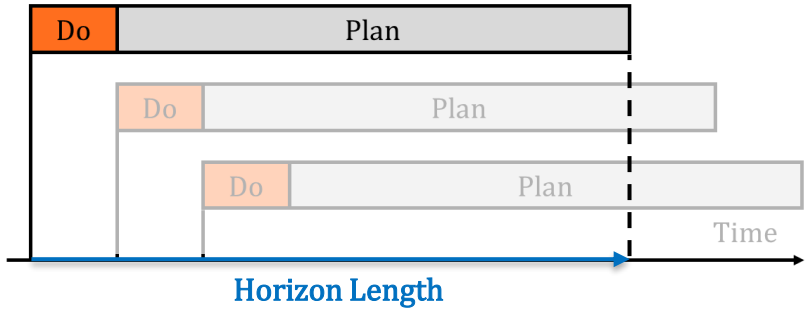


Results - Metrics

Ryzen 9 5950x at 10 SQP Iterations

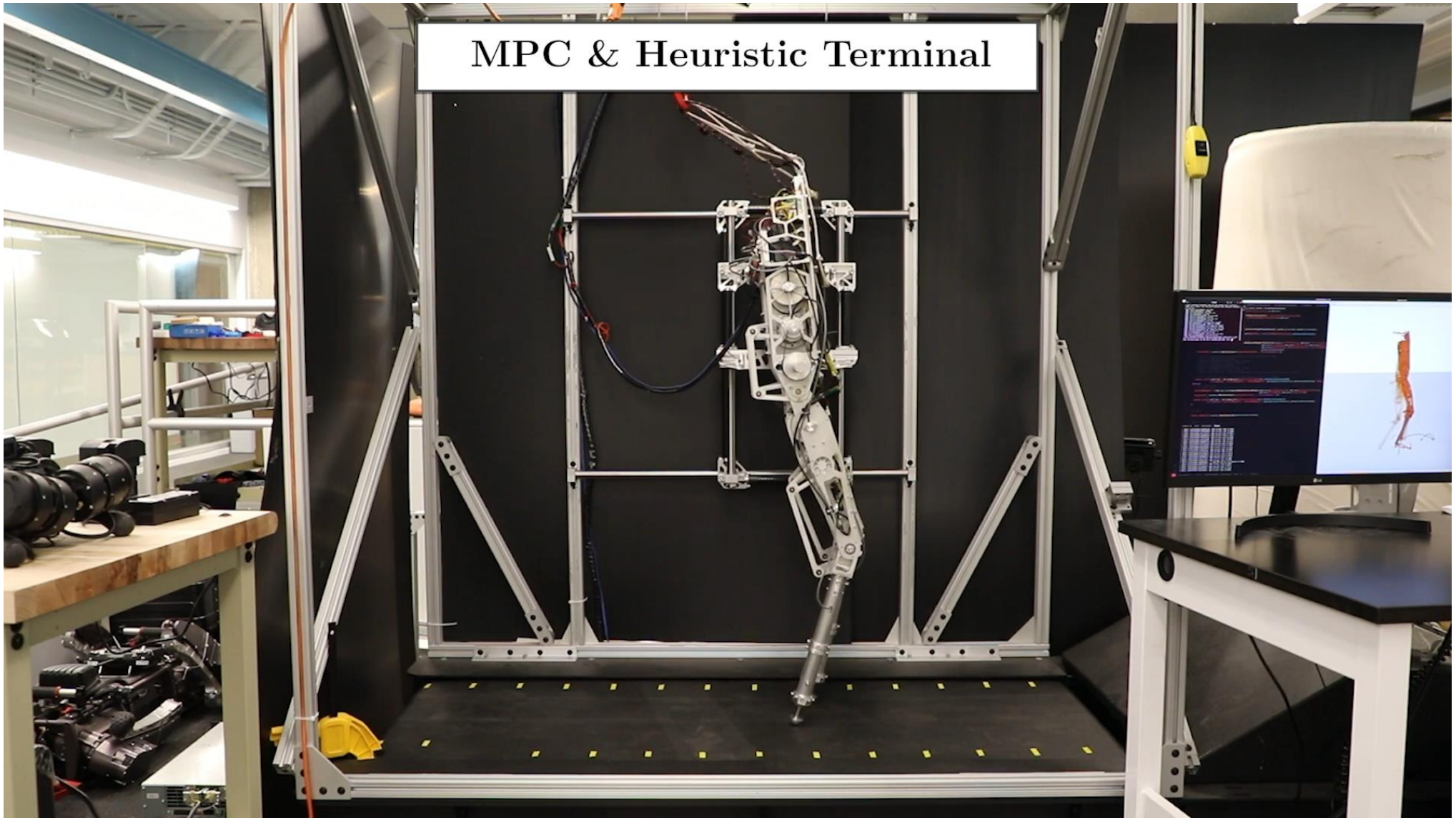
Horizon Length [s]	2.0	1.0	0.5	0.2
MPC Frequency [Hz]	270	480	670	850



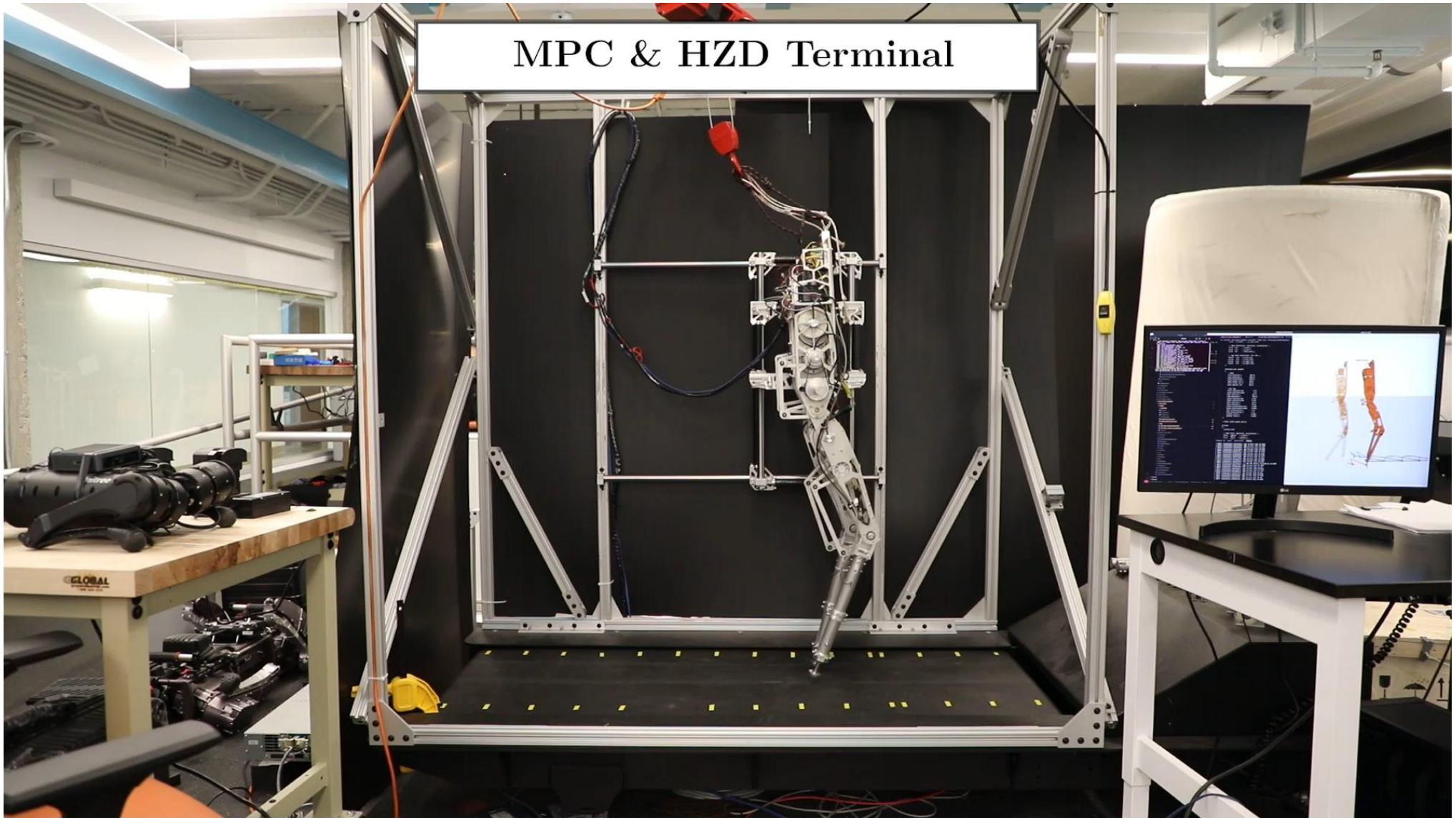


Reduce computational complexity through terminal

Results



Results – MPC & HZD Terminal



Thank you for your Attention!

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Links

Paper:

https://arxiv.org/abs/2203.07429

Video:

https://www.youtube.com/watch?v=3g8ZNsCWdOA

Website:

https://galliker.tech/

https://noelc-s.github.io/website/