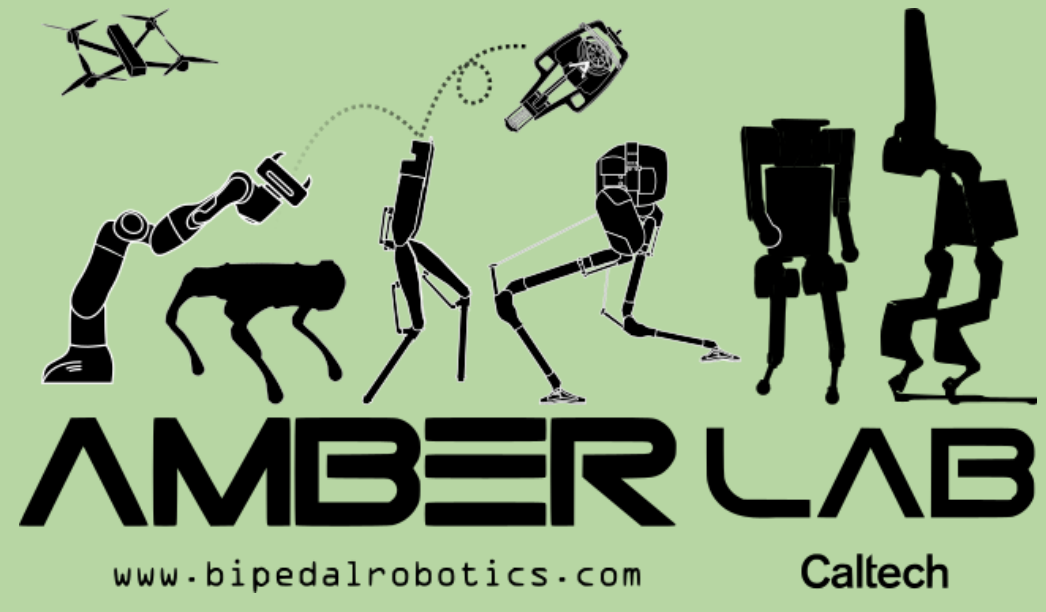




Hierarchical Reduced-Order Model Predictive Control for Robust Locomotion on Humanoid Robots

Caltech

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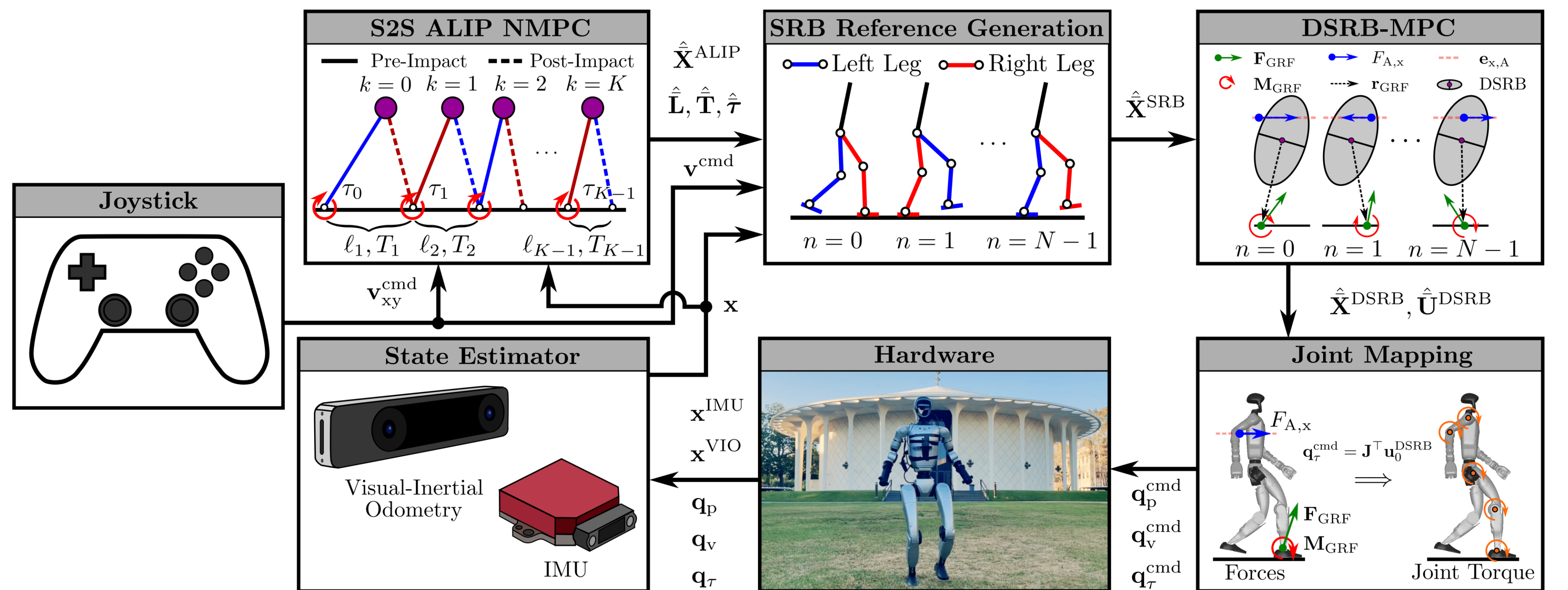
Motivation

Bridge the gap between fast ROM control and more versatile whole body control for humanoid locomotion

Overview

- High level ALIP NMPC step planner
- Mid level decomposed SRB – MPC
- Experimental validation

Control Architecture



High Level Planner - ALIP S2S NMPC

$$\min_{\mathbf{x}^{\text{ALIP}}, \ell, \mathbf{T}, \tau} \sum_{k=0}^{K-1} \|\tilde{\mathbf{x}}_{k+1}^{\text{ALIP}}\|_{\mathbf{Q}_x} + \|\tilde{\ell}_k\|_{\mathbf{R}_\ell} + \|\tilde{T}_k\|_{\mathbf{R}_T} + \|\tau_k\|_{\mathbf{R}_\tau}$$

$$\text{s.t.} \quad \text{Eq. (11),} \quad k \in \{1, \dots, K-1\}$$

$$\mathbf{x}_{\text{lb}}^{\text{ALIP}} \leq \mathbf{x}_k^{\text{ALIP}} \leq \mathbf{x}_{\text{ub}}^{\text{ALIP}}, \quad k \in \{1, \dots, K\}$$

$$\ell_{\text{lb}} \leq \ell_k \leq \ell_{\text{ub}}, \quad k \in \{0, \dots, K-1\}$$

$$T_{\text{lb}} \leq T_k \leq T_{\text{ub}}, \quad k \in \{0, \dots, K-1\}$$

$$\tau_{\text{lb}} \leq \tau_k \leq \tau_{\text{ub}}, \quad k \in \{0, \dots, K-1\}$$

$$\mathbf{x}_1^{\text{ALIP}} = \Phi(T_0 - t_{\text{curr}}) \mathbf{x}_0^{\text{ALIP}} + \Gamma(T_0 - t_{\text{curr}}) \tau_0$$

Mid Level Planner – SRB-MPC

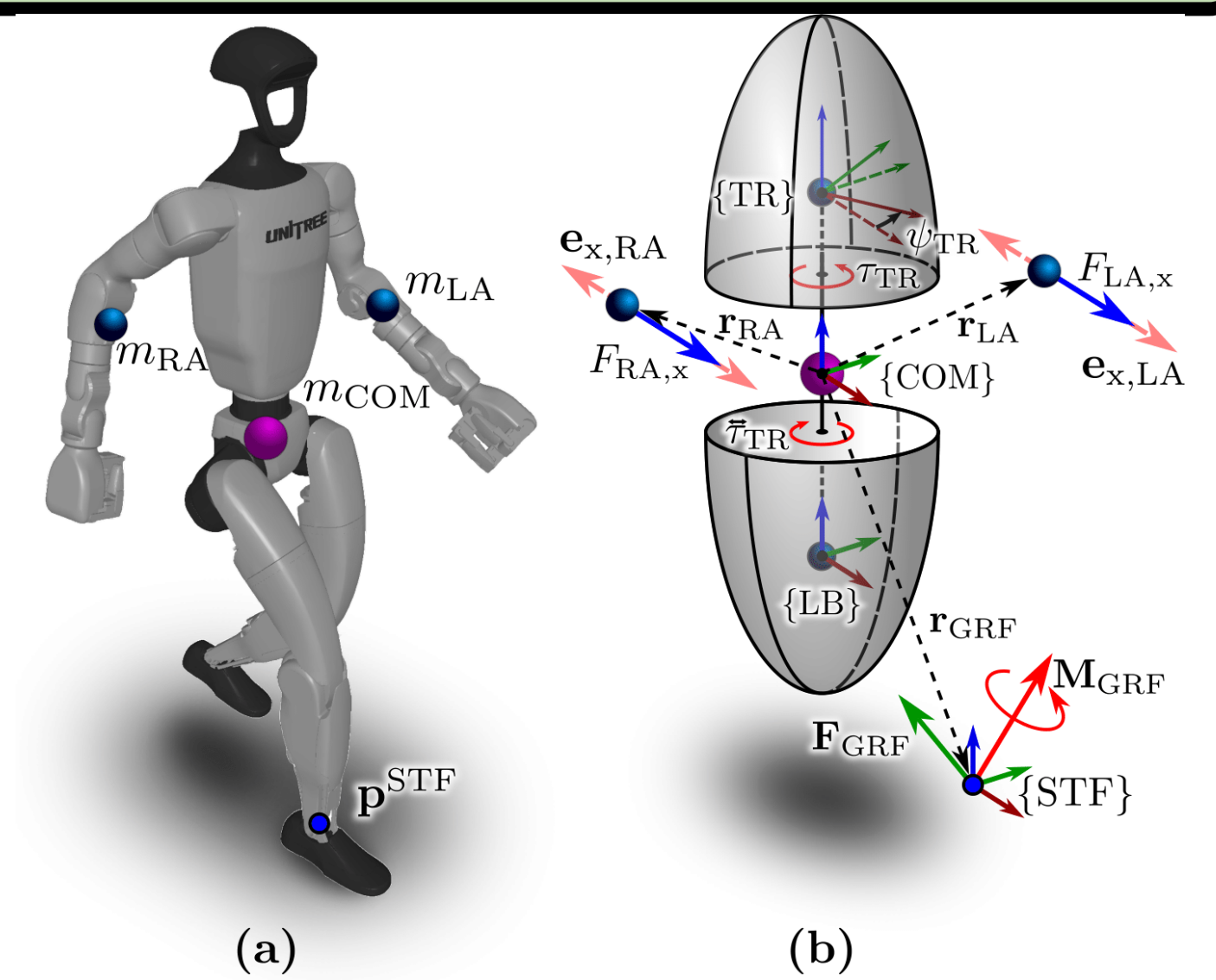
$$\min_{\mathbf{x}^{\text{SRB}}, \mathbf{u}^{\text{SRB}}} \sum_{n=0}^{N-1} \|\mathbf{x}_{n+1}^{\text{SRB}} - \bar{\mathbf{x}}_{n+1}^{\text{SRB}}\|_{\mathbf{Q}^{\text{SRB}}} + \|\mathbf{u}_n^{\text{SRB}}\|_{\mathbf{R}^{\text{SRB}}}$$

$$\text{s.t.} \quad \mathbf{x}_{n+1}^{\text{SRB}} = \mathbf{A}_n^{\text{SRB}} \mathbf{x}_n^{\text{SRB}} + \mathbf{B}_n^{\text{SRB}} \mathbf{u}_n^{\text{SRB}},$$

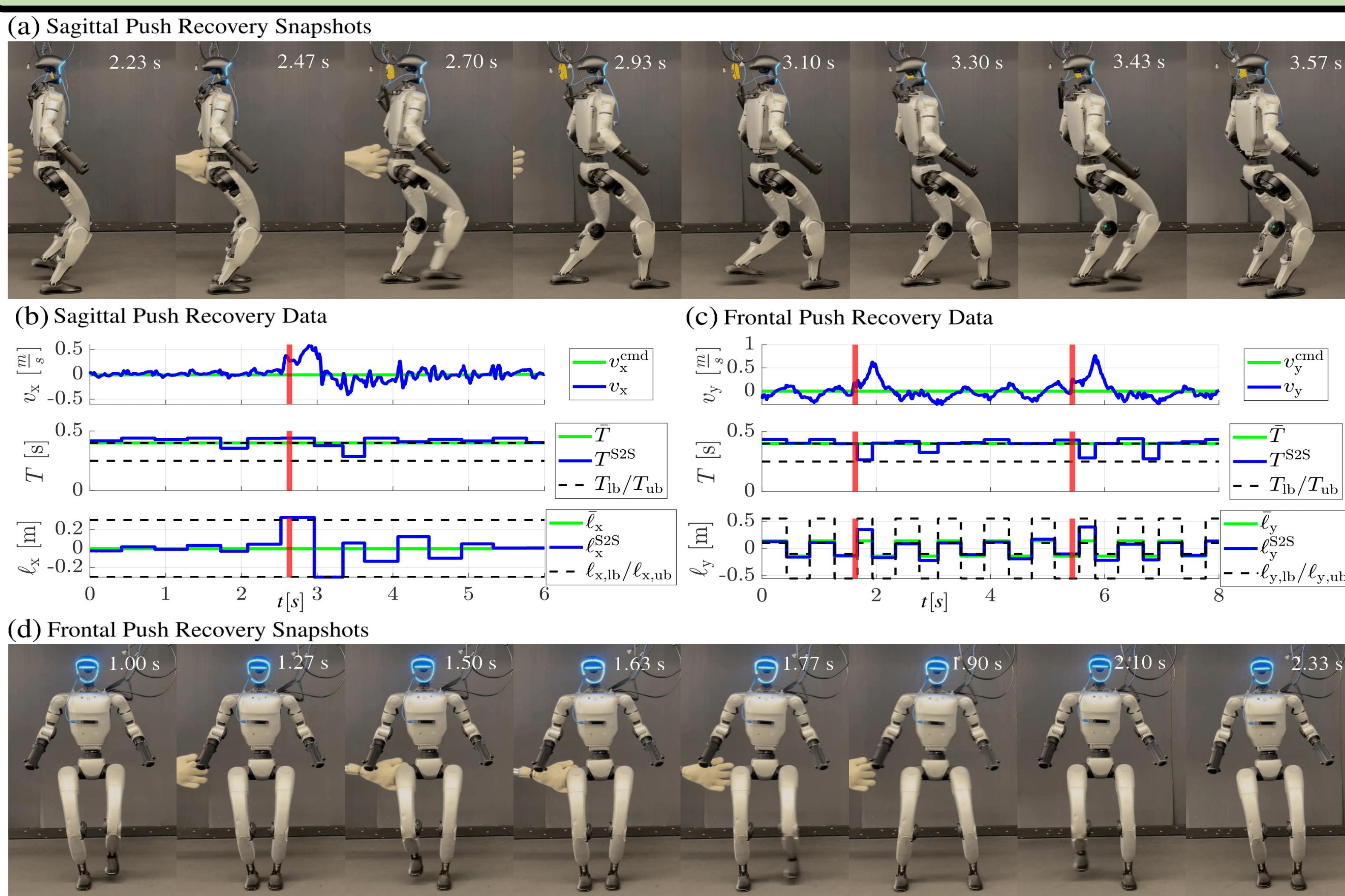
$$\mathbf{C}_n^{\text{SRB}} \mathbf{u}_n^{\text{SRB}} \leq \mathbf{c}_n^{\text{SRB}},$$

$$\mathbf{D}_n^{\text{SRB}} \mathbf{u}_n^{\text{SRB}} = 0,$$

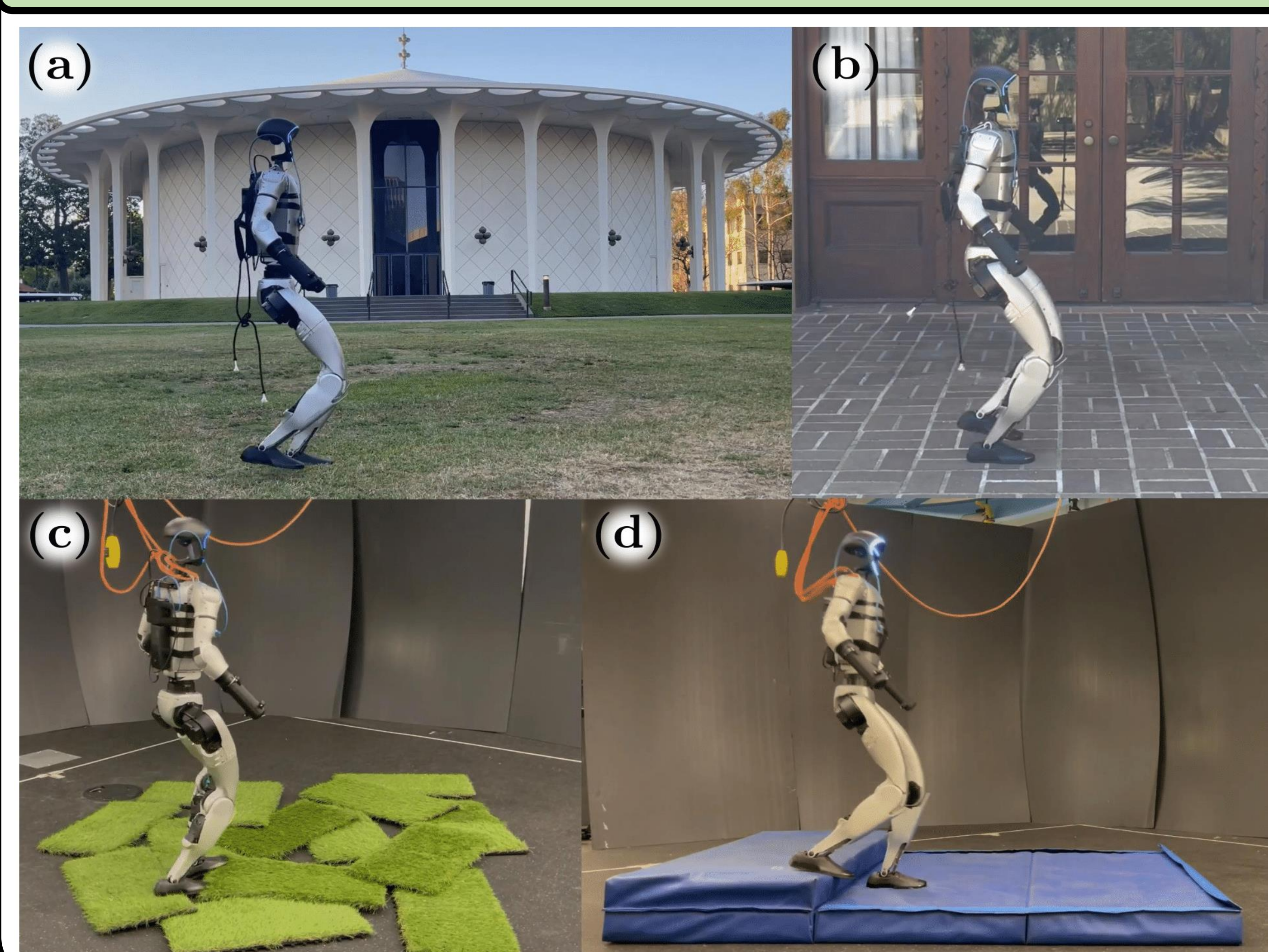
Decomposed SRB Model



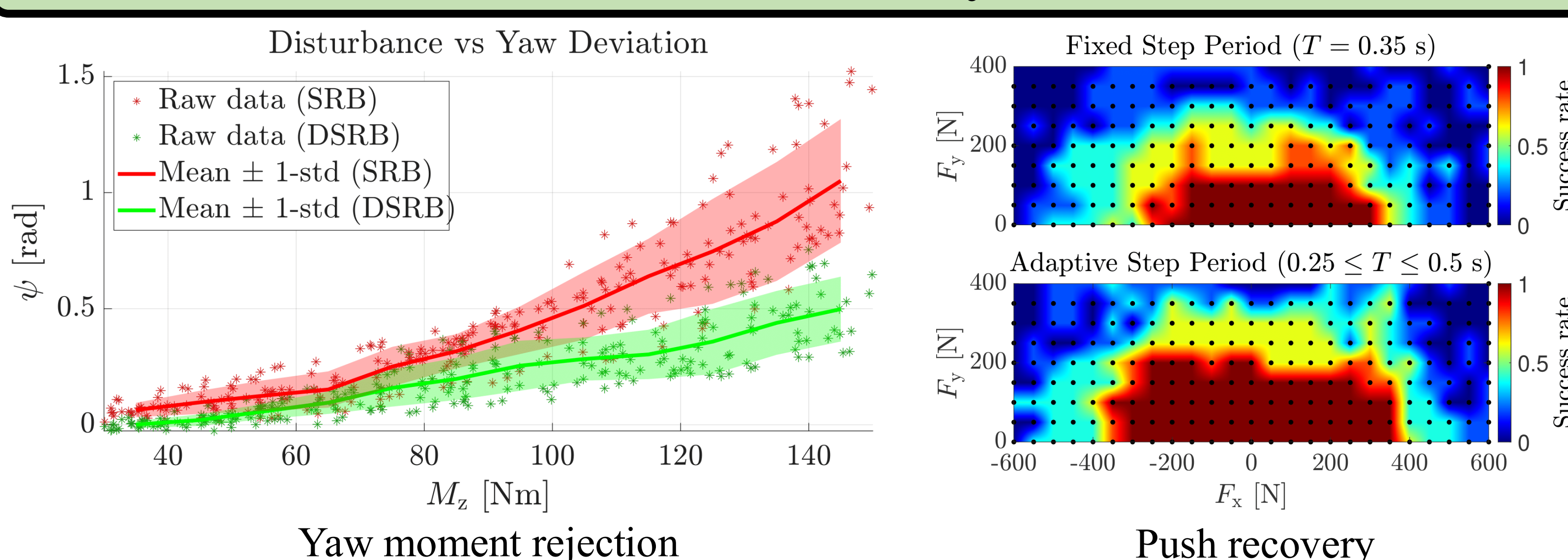
Push Recovery Experiments



Terrain Traversal Experiments



Robustness Analysis



Key Takeaways

- Step period optimization increases flexibility and robustness
- Upper body control can help stabilizing the system
- Constraining the arm motion limits versatility

Project Page

<https://adrianghansah.github.io/H-RO-MPC/>

