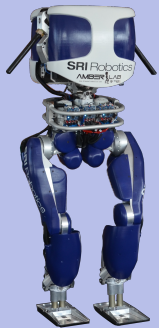**DURUS**

dynamic spring-legged humanoid robot

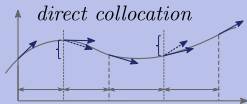**Hybrid zero dynamics framework**

full-order dynamics
$$D(q)\ddot{q} + H(q,\dot{q}) = B_v u_v + J_v^T(q) F_v$$
$$J_v(q)\ddot{q} + \dot{J}_v(q,\dot{q})\dot{q} = 0$$

virtual constraints
$$y^a - y^d(\alpha) = 0$$

Nonlinear optimization formulation

direct collocation

$$\underset{\mathbf{z}^*}{\operatorname{argmin}} \sum_{v=1}^{p} \mathcal{J}_v(\mathbf{z}_v)$$

$$\text{s.t} \quad \mathbf{z}_{\min} \leq \mathbf{z} \leq \mathbf{z}_{\max},$$
$$\mathbf{c}_{\min} \leq \mathbf{c}(\mathbf{z}) \leq \mathbf{c}_{\max},$$

$$z_v^i = (T^{I,v}, q^i, \dot{q}^i, \ddot{q}^i, u_v^i, F_v^i, \alpha_v^i, v_d^i, \beta_v^i)$$

3D dynamic walking