MECHANICAL ENGINEERING
TEXAS A&M UNIVERSITY

HUMAN REHABILITATION (HUR) Group

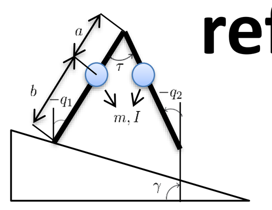
A Direct Method of Trajectory Optimization for Compass Bipedal Locomotion under Terrain Uncertainty

Kenneth Yi-wen Chao and Pilwon Hur, Ph.D.

kchao@tamu.edu, pilwonhur@tamu.edu http://hurgroup.net

Research Highlights

- Objective: generate a robust walking trajectory under terrain uncertainty.
- A method for compass gait generation which incorporates:
  1) Trajectory optimization with **direct collocation** (can be scaled well to high dimensional problems [1,2]).
  2) A **robust cost** in optimization to **reflect the walking robustness** [3].

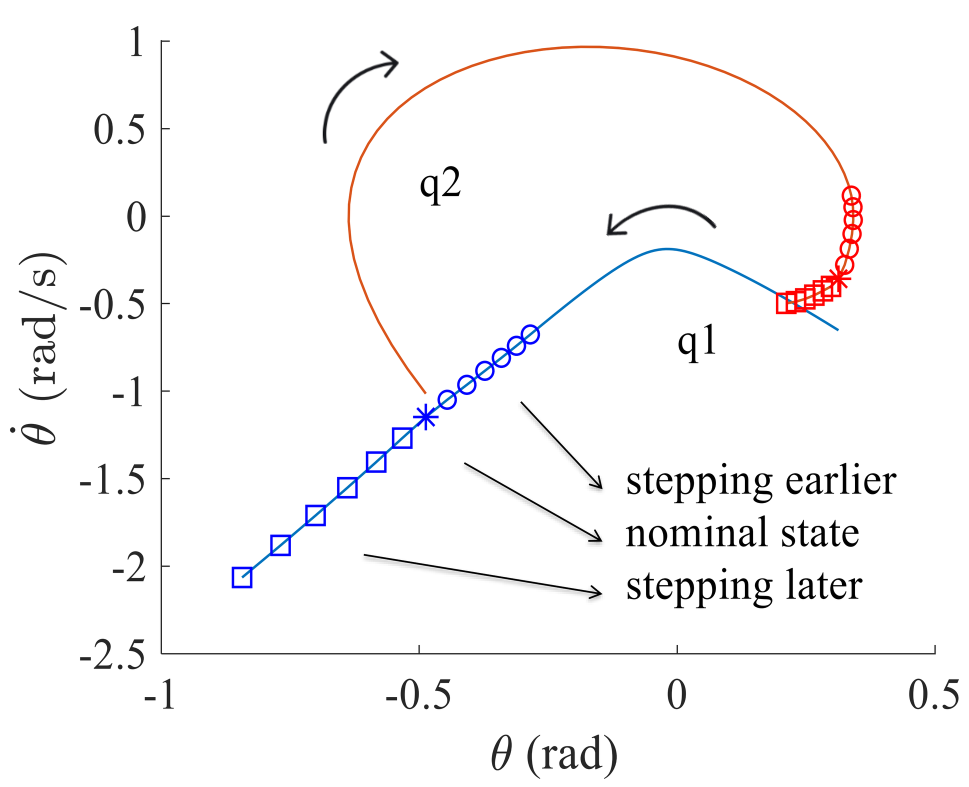


Walking Robustness

The walking robustness is quantified by calculating the distance between the post-impact state $\Delta(x_i)$ and its projection on the nominal trajectory $\Pi(\Delta(x_i))$ [3].

Main Idea

Evaluate the walking robustness of heel-strike by sampling stepping time near nominal step time t_F!



Optimization Formulation

- With $x = [x_1, \ldots, x_N]$, $u = [u_1, \ldots, u_N]$ and t_F as free variables, the optimization can be expressed as:

$$\min_{x,u,t_F} \quad J_0(x,u) + \omega \sum_{i=k-d}^{k+d=N} J_i(x_i,u_i)$$

$$\text{s.t.} \quad \Delta(x_k) = x_1$$

where

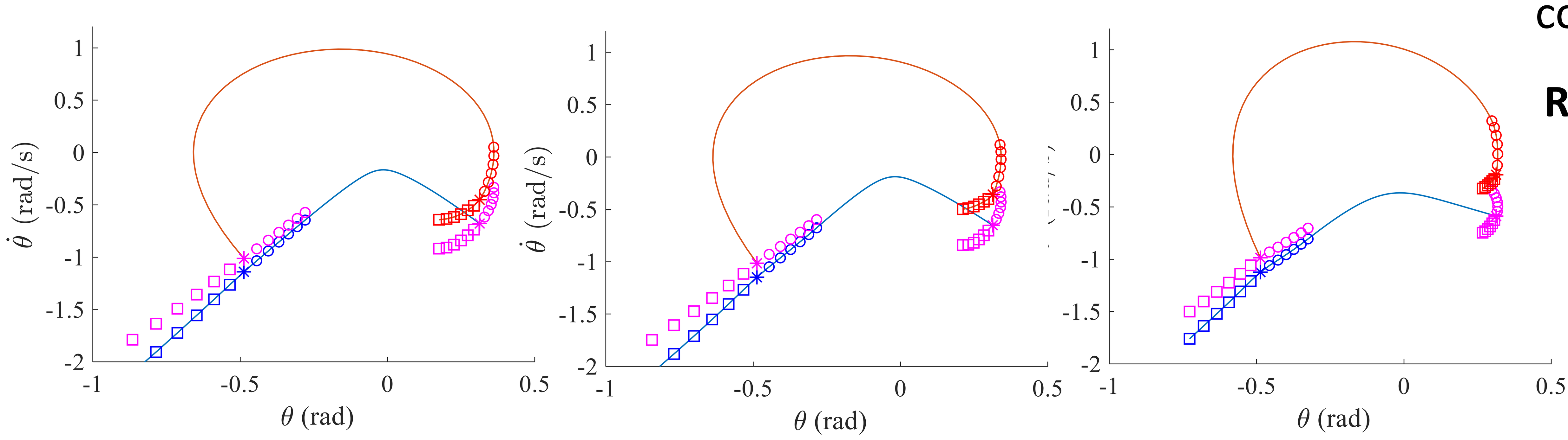
$$J_i = (\Delta(x_i) - \Pi(\Delta(x_i)))^T P(\Delta(x_i) - \Pi(\Delta(x_i))),\ P = P^T > 0$$

- $\Delta()$ is the function of impact dynamics with state relabeling for calculating post-impact states
- $\omega \sum J_i()$ **is the walking robust cost** for compass gait by evaluating the walking robust cost associated to the set of sampled stepping time.

Generated Optimal Trajectories

- The following results are the optimal trajectories solved using MATLAB and OptimTraj [5] with different weights of the walking robust cost.
- <u>The higher the weight, the closer the nearby states towards the initial condition.</u>

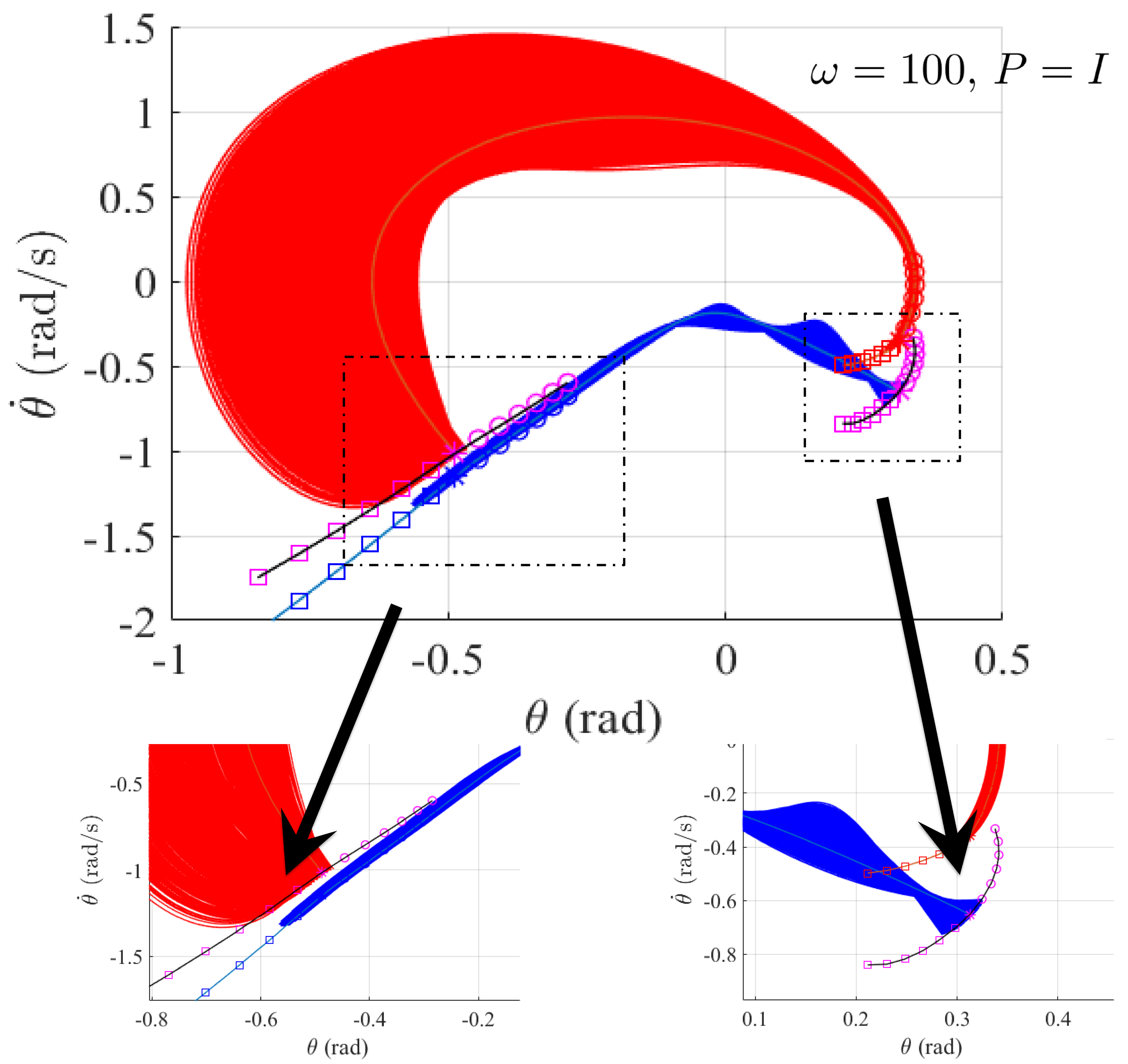
Sampled stepping time: $t_F \pm 10\% t_F$



$\omega = 0,\ P = I$ $\omega = 100,\ P = I$ $\omega = 500,\ P = I$

Simulation Result

- Walking simulation for 1000 steps using MATLAB and ode45 with slope variation.
- Time-varying LQR is implemented.



Future Works

- Test this method with more feasibility constraints (e.g. torque constraint and contact force constraint) and more complicated bipedal robots.

References

[1] M. Posa et al., *In JIRR (2014).*
[2] Z. Manchester et al., *In RSS (2017).*
[3] H. Dai et al., *In CDC (2012).*
[4] B. Griffin et al., *In JIRR, (2017).*
[5] M. Kelly, A trajectory optimization library for Matlab @ GitHub.