Leg Shaping and Event-Driven Control of A Small-Scale, Low-DoF Two-Mode Robot

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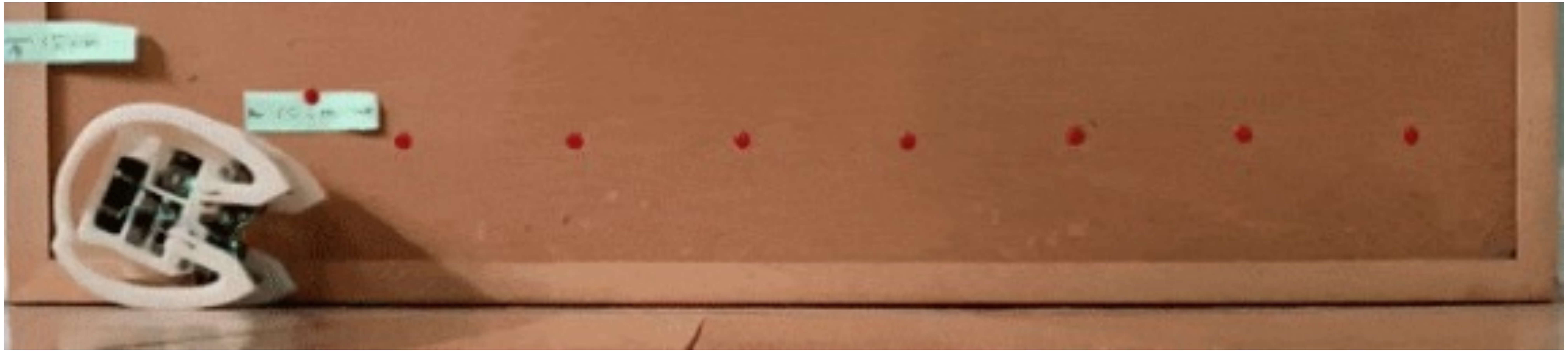
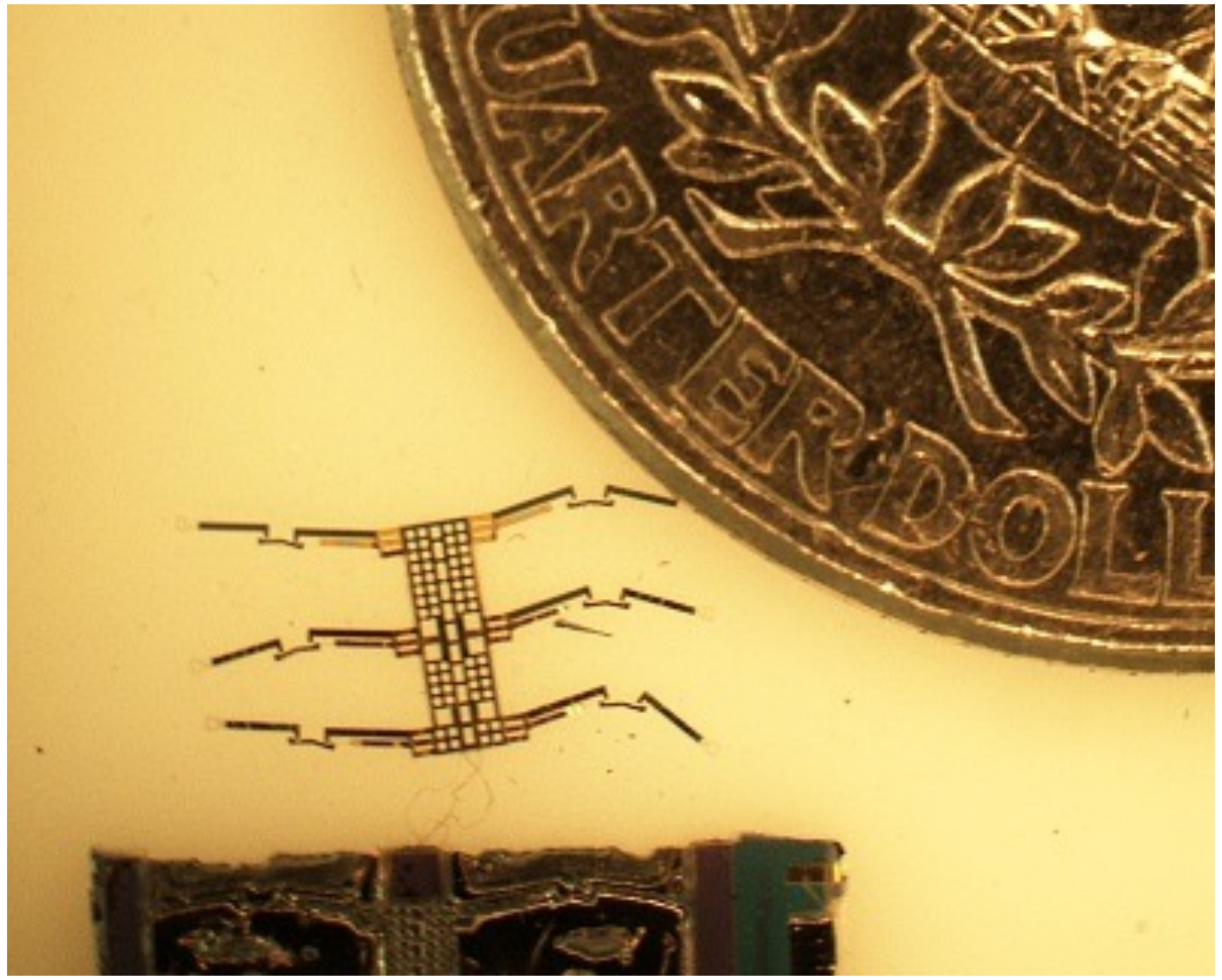
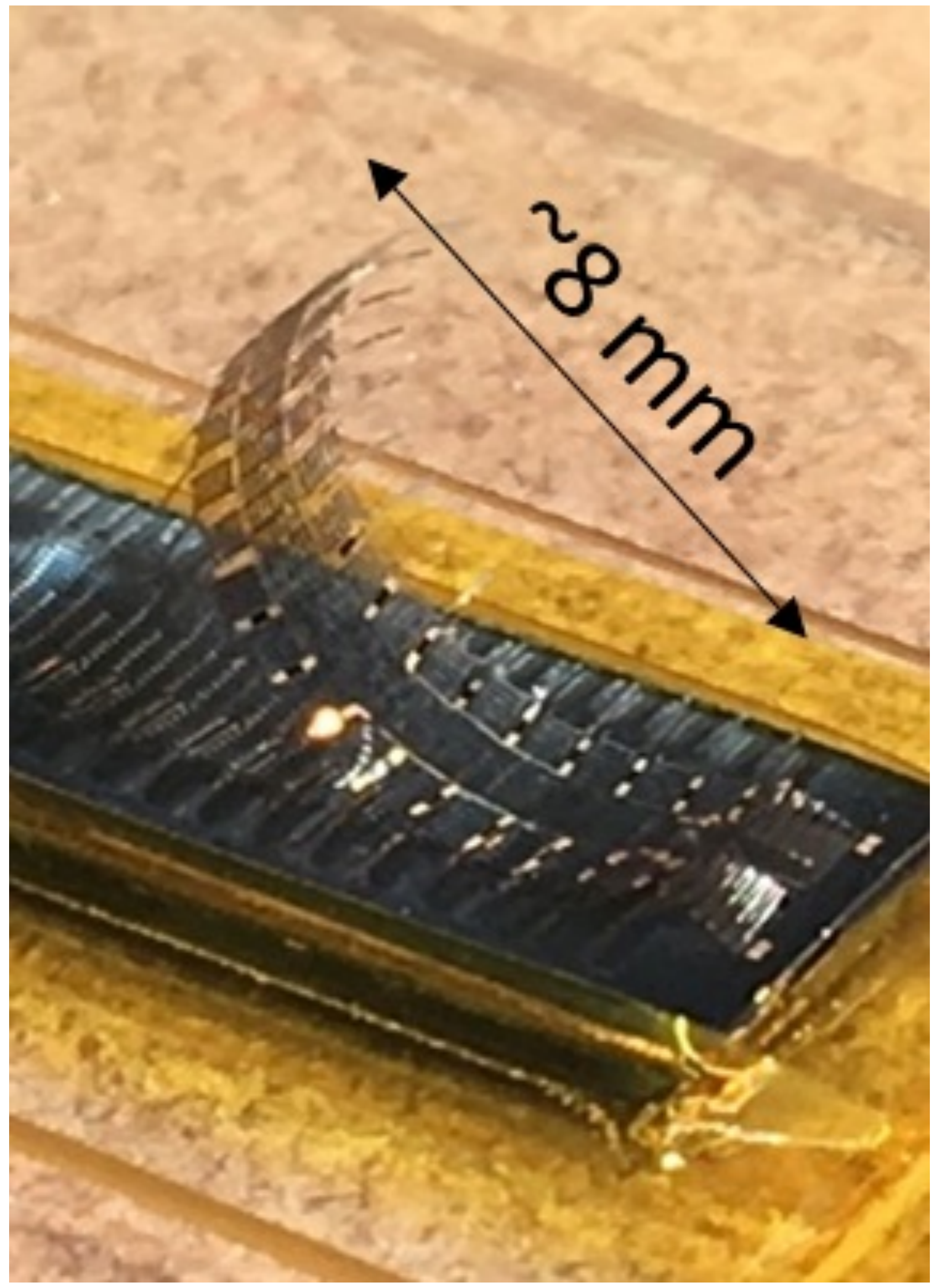


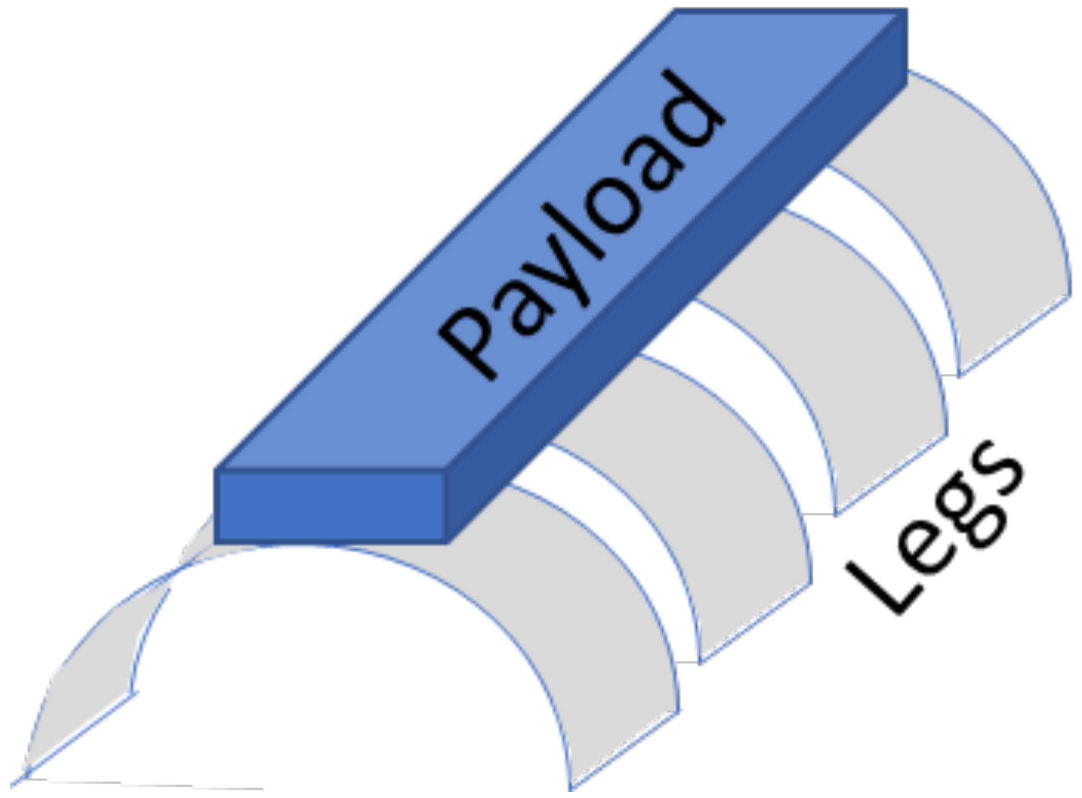
Agenda

- Motivation
- Leg Geometry Design
- Controller Design
- Prototyping
- Results
- Conclusions

Miniaturizing mobile robots offers potential benefits for portability, cost, and access to confined spaces



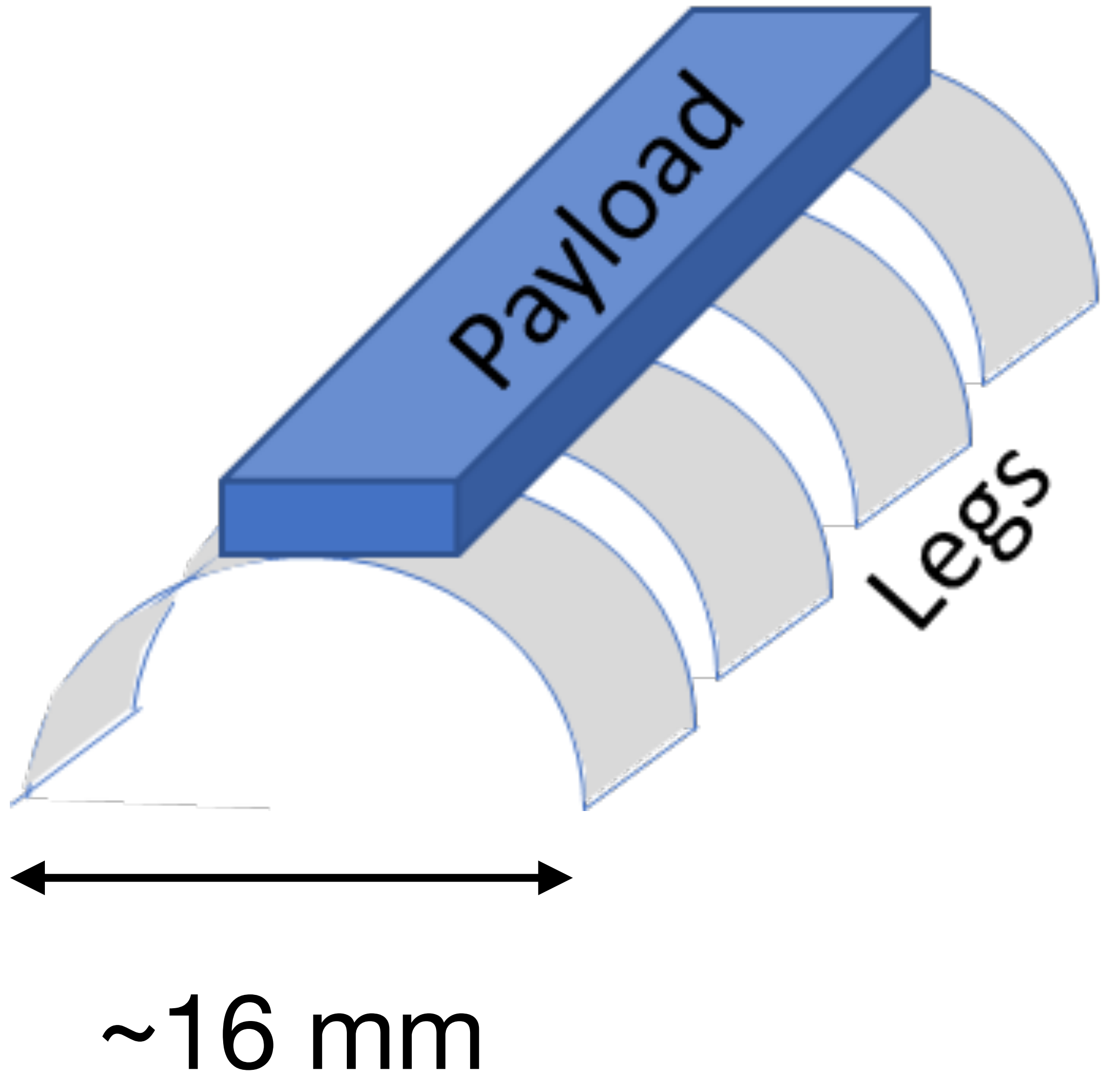


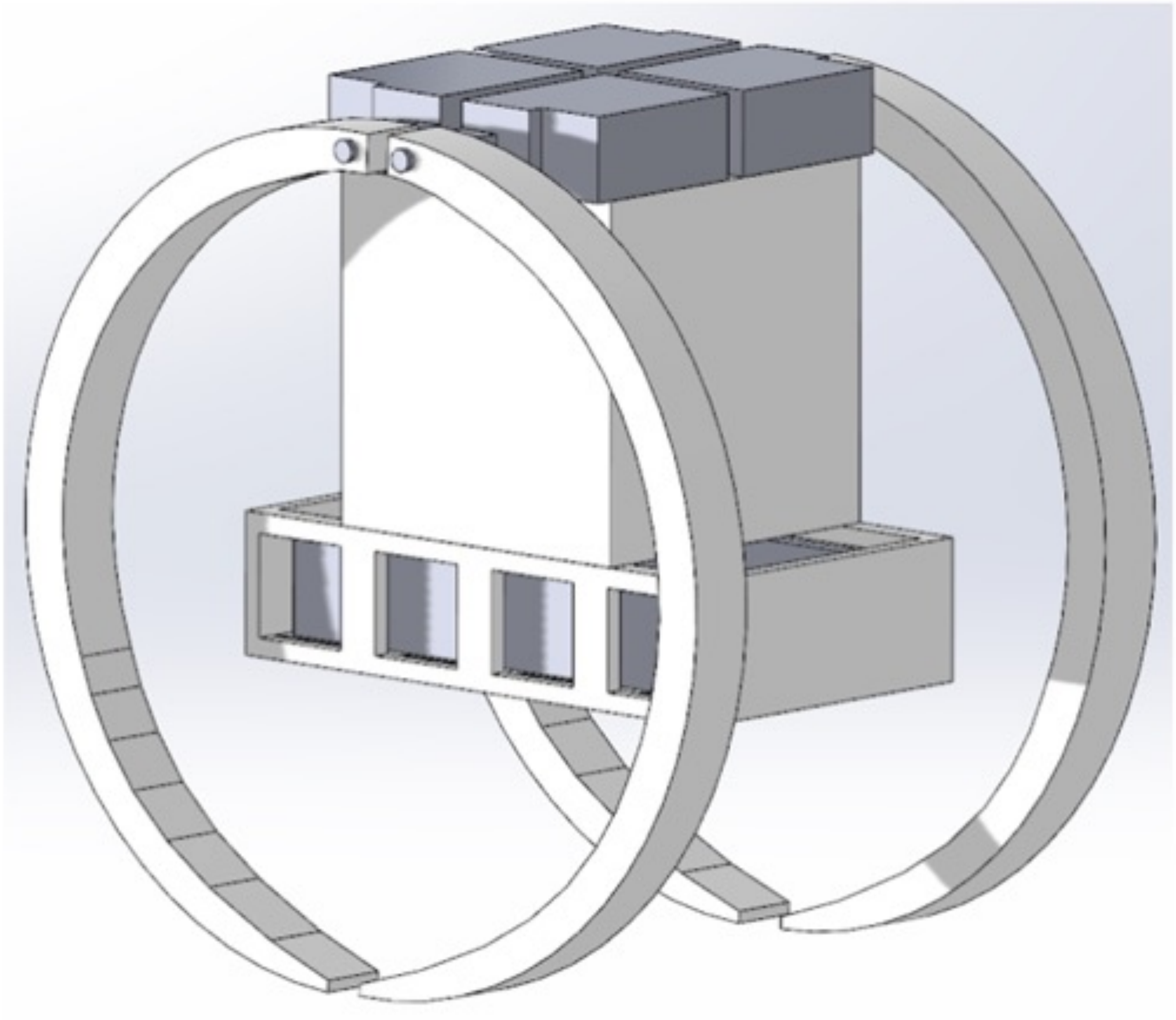


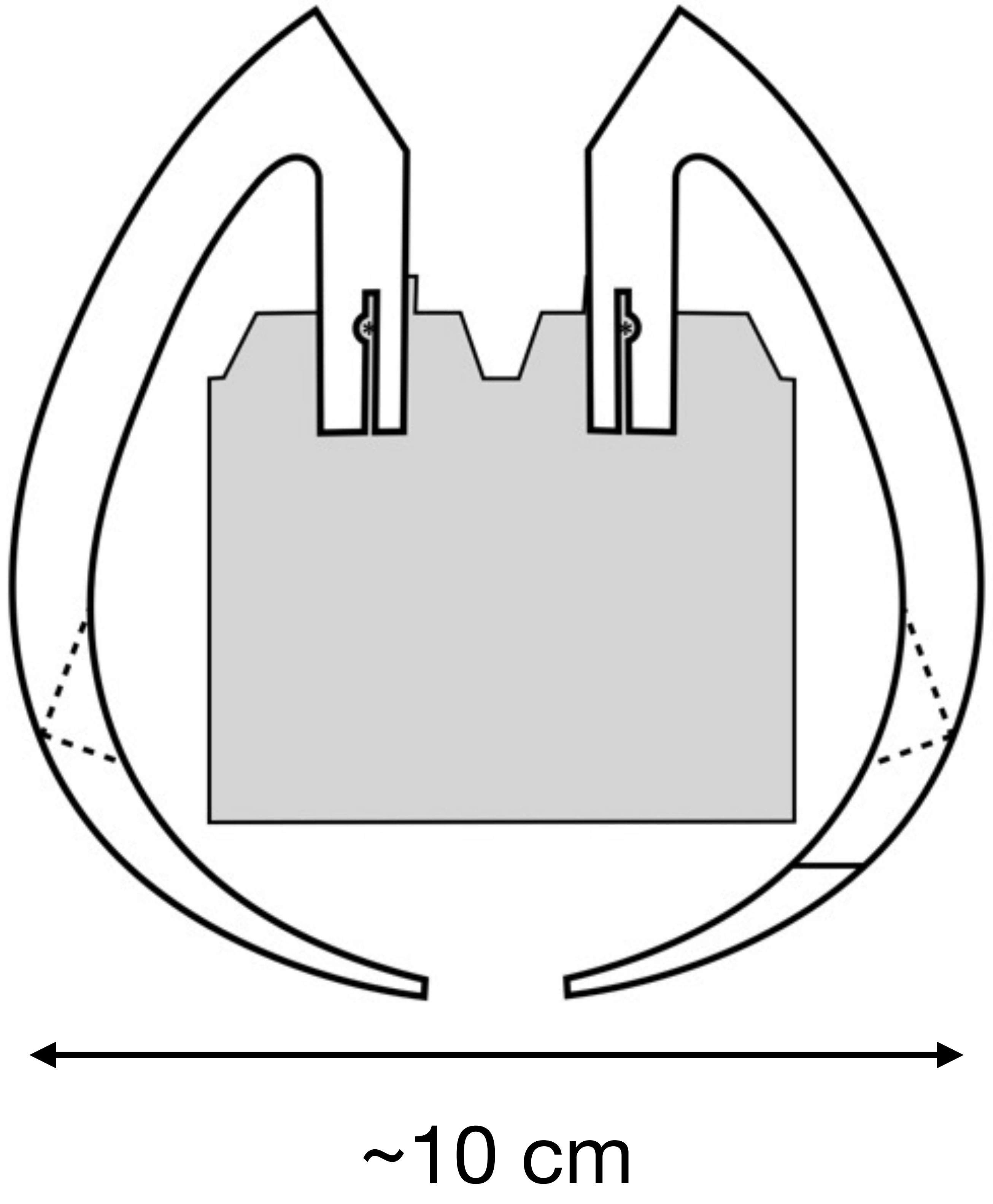
Piezo-electric microactuators in micro-electro-mechanical fabrication systems

How would it move? What would a meso-scale realization be?

Micro-scale to Meso-scale: From continuous bending to curved appendage moving about an axis







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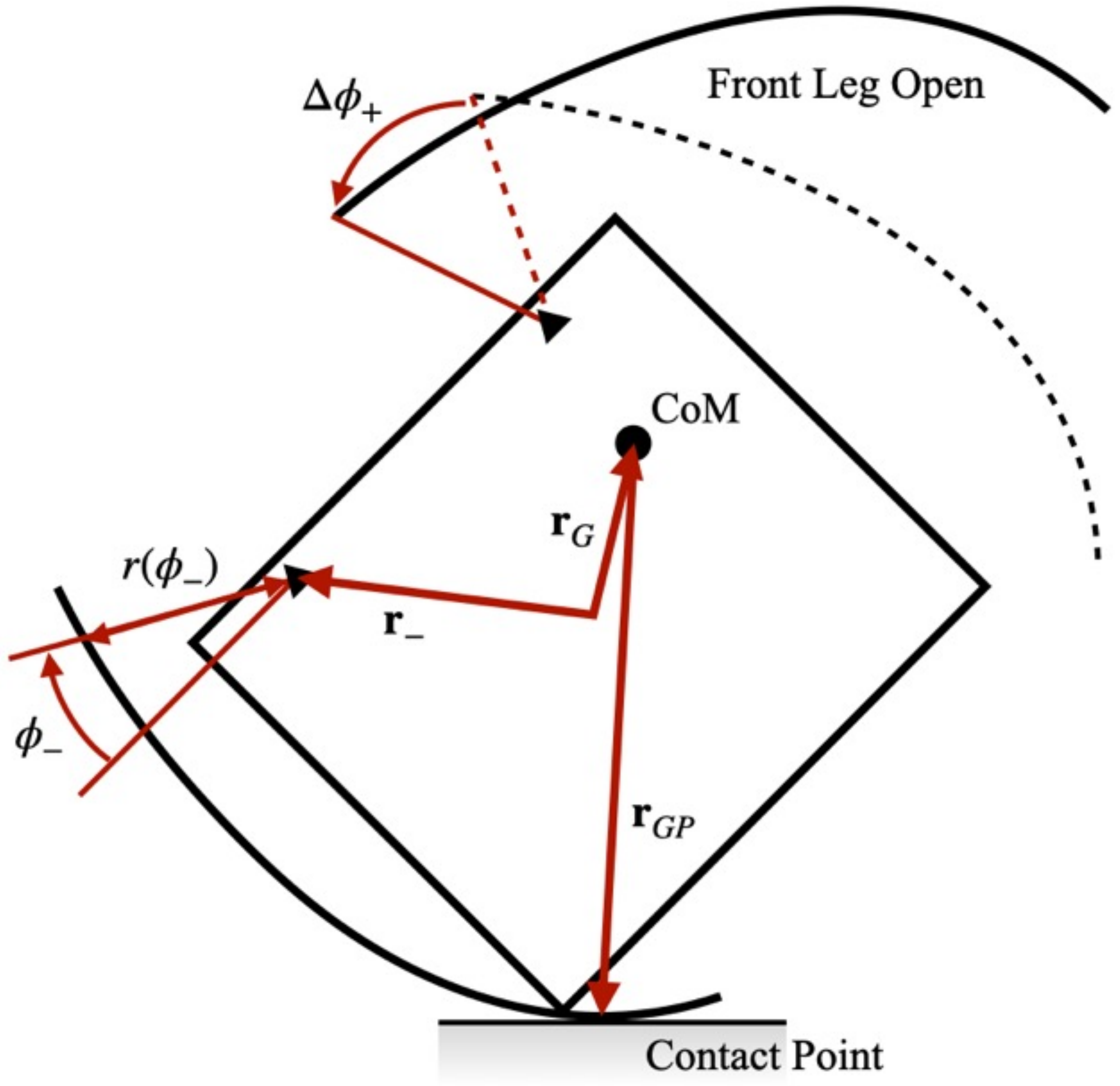
We isolate the contribution of gravity to simplify metrics for leg geometries that facilitate whole-body rolling



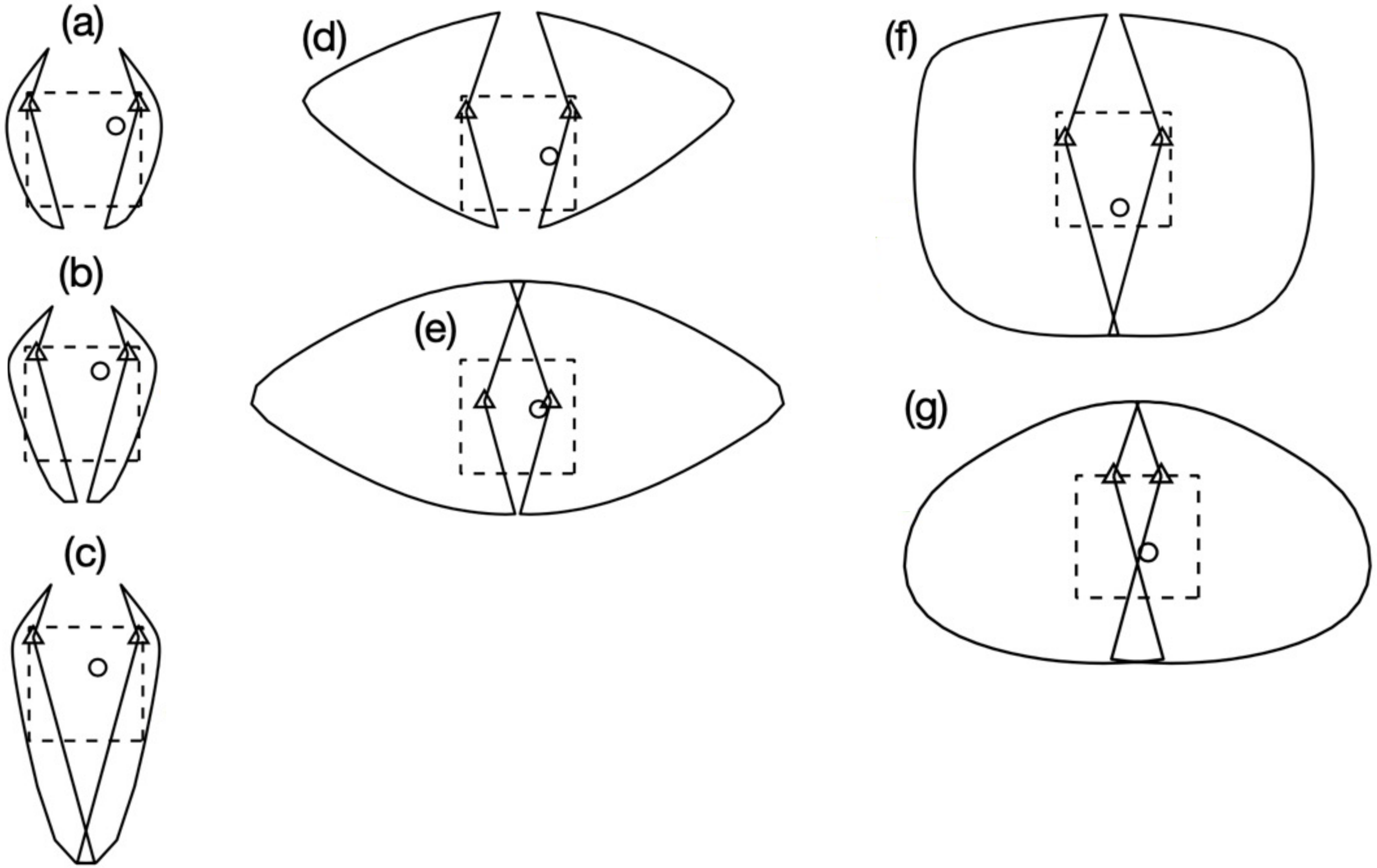
J_1: gravitational contribution to clockwise rotation (as negative as possible)

$$J_1 = \int_{-\pi}^{\pi} \min_{\Delta\phi} r_{GP}(\theta_G, \Delta\phi) d\theta_G \tag{2}$$

$$J_2 = \int_{-\pi}^{\pi} \left| \frac{d}{d\theta_G} \arg\min_{\Delta\phi} r_{GP}(\theta_G, \Delta\phi) \right| d\theta_G \tag{3}$$

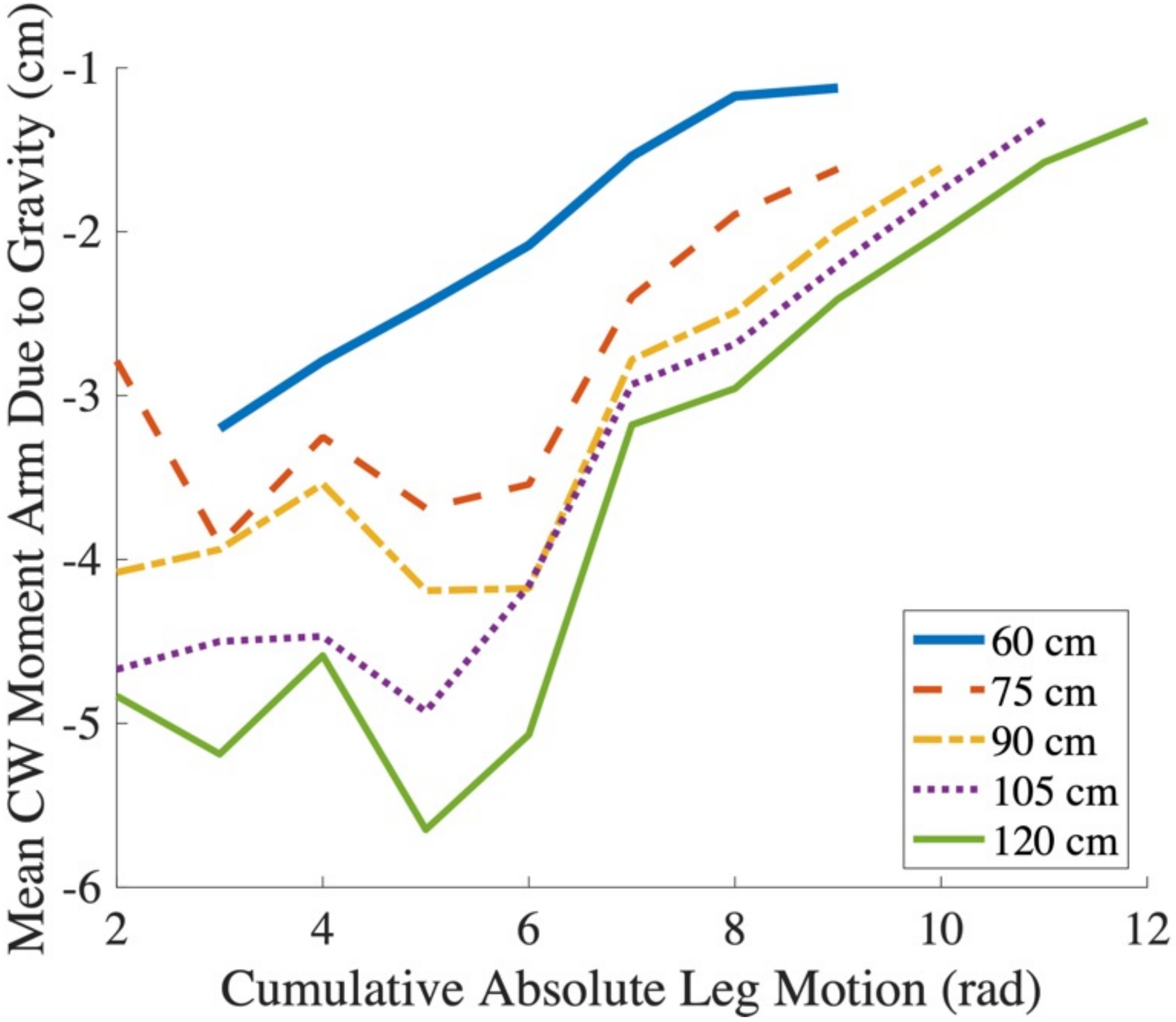
J_2: actuation effort (as small as possible)

We proposed thousands of candidates for the robot's geometry



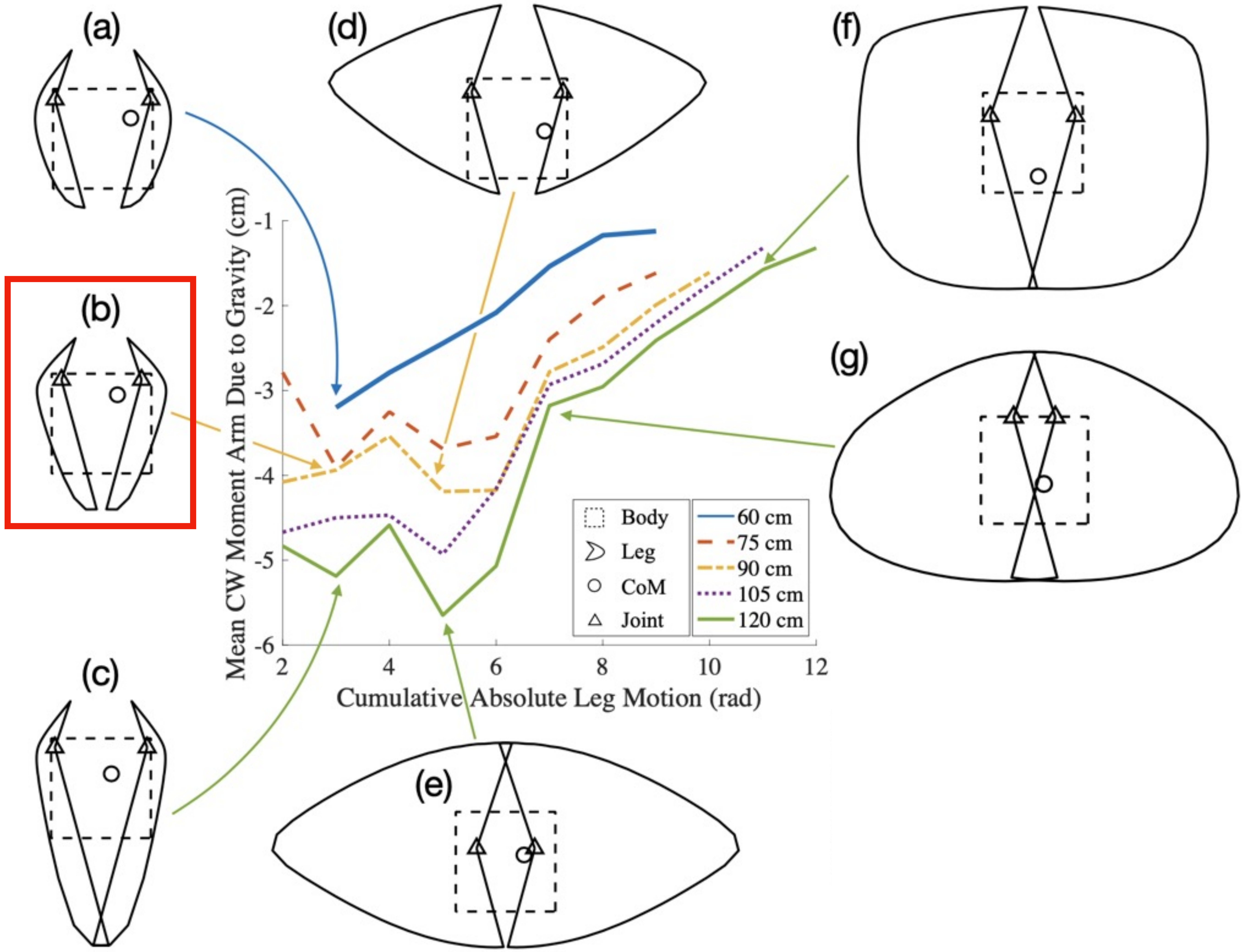
We calculate J_1 and J_2 of each candidate robot geometry and grouped them by the maximum leg dimension

J_1: gravitational contribution to clockwise rotation (as negative as possible)



J_2: actuation effort

Leg shape like an inverted pendulum is promising for efficient rolling



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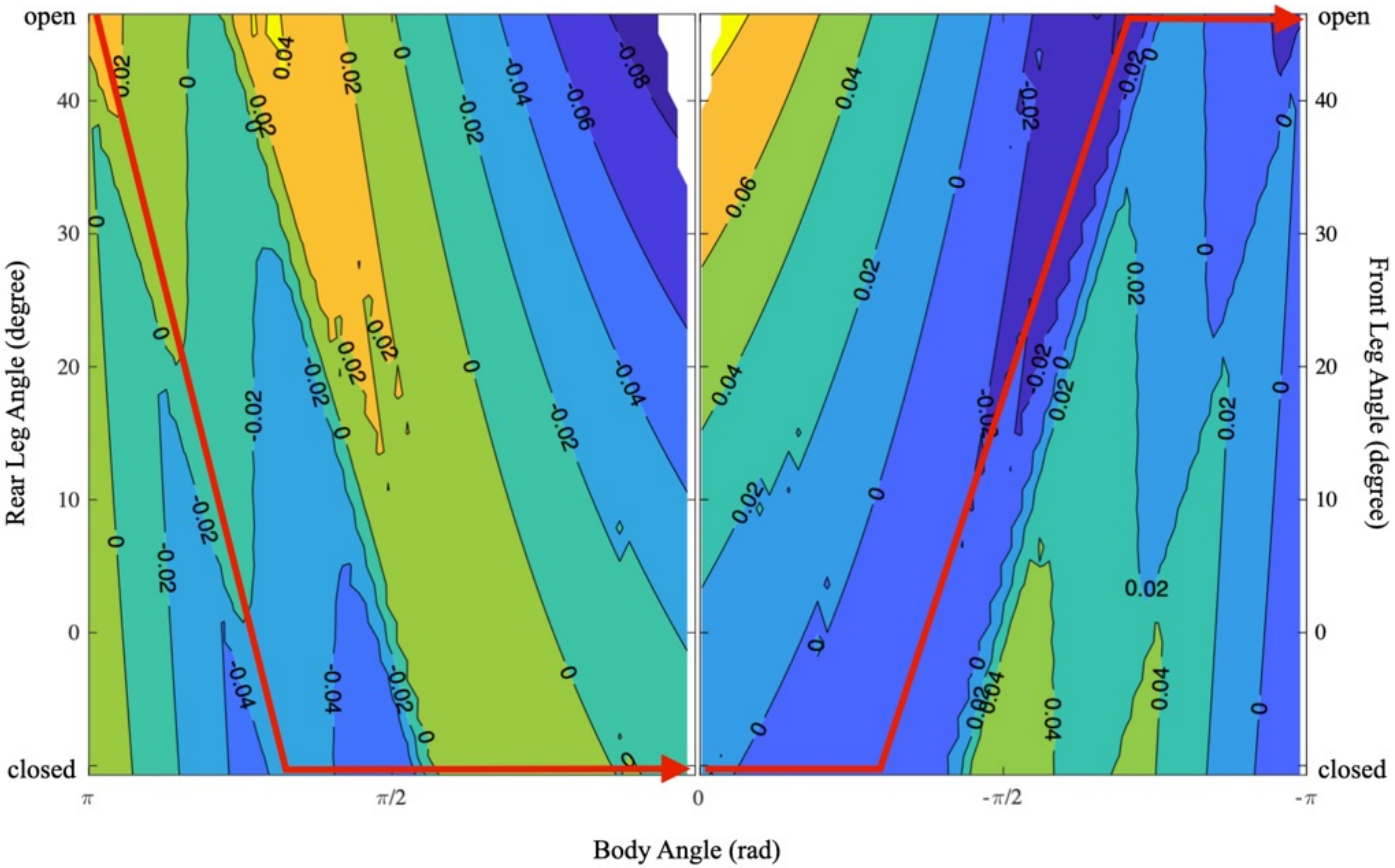
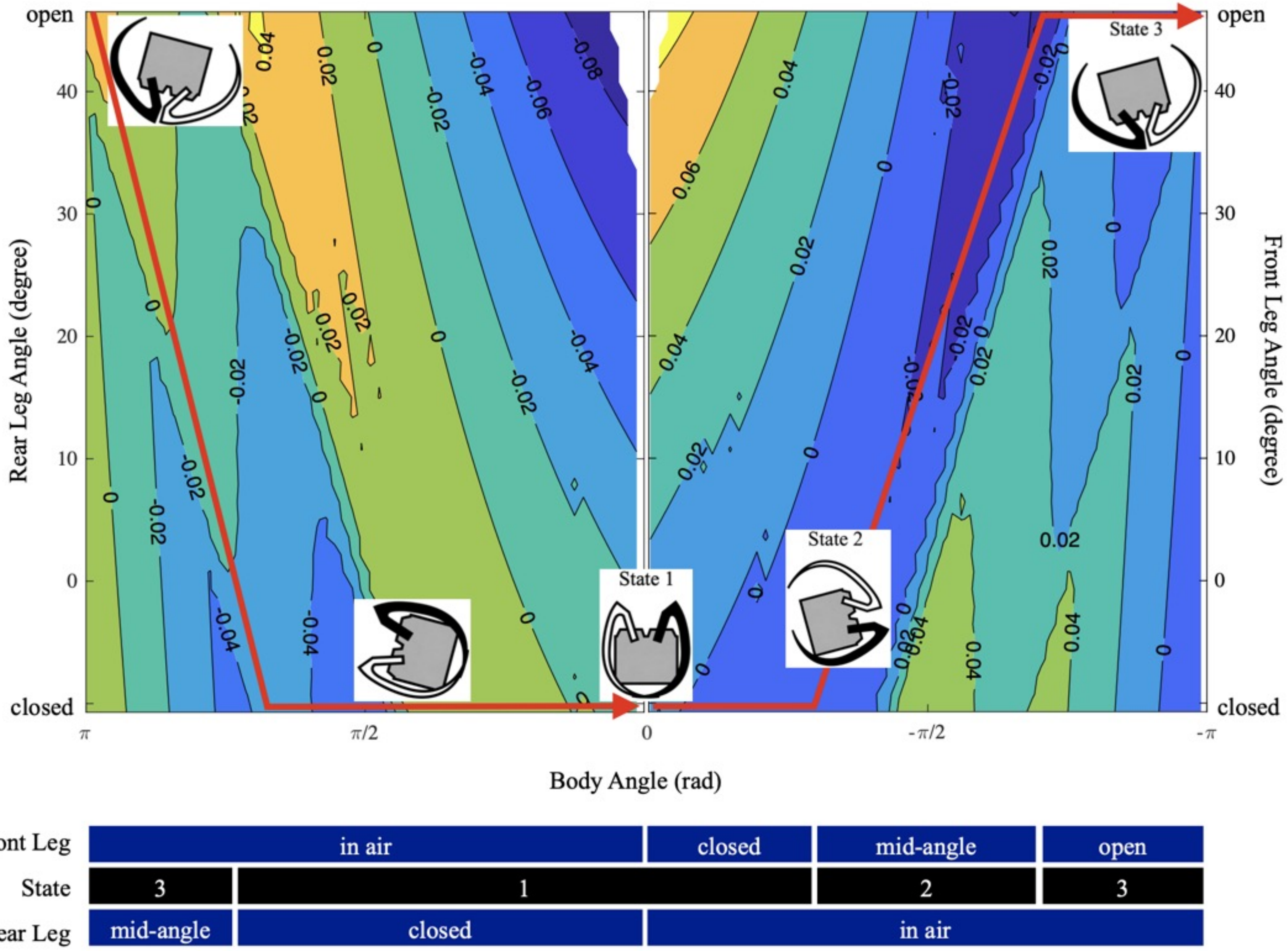
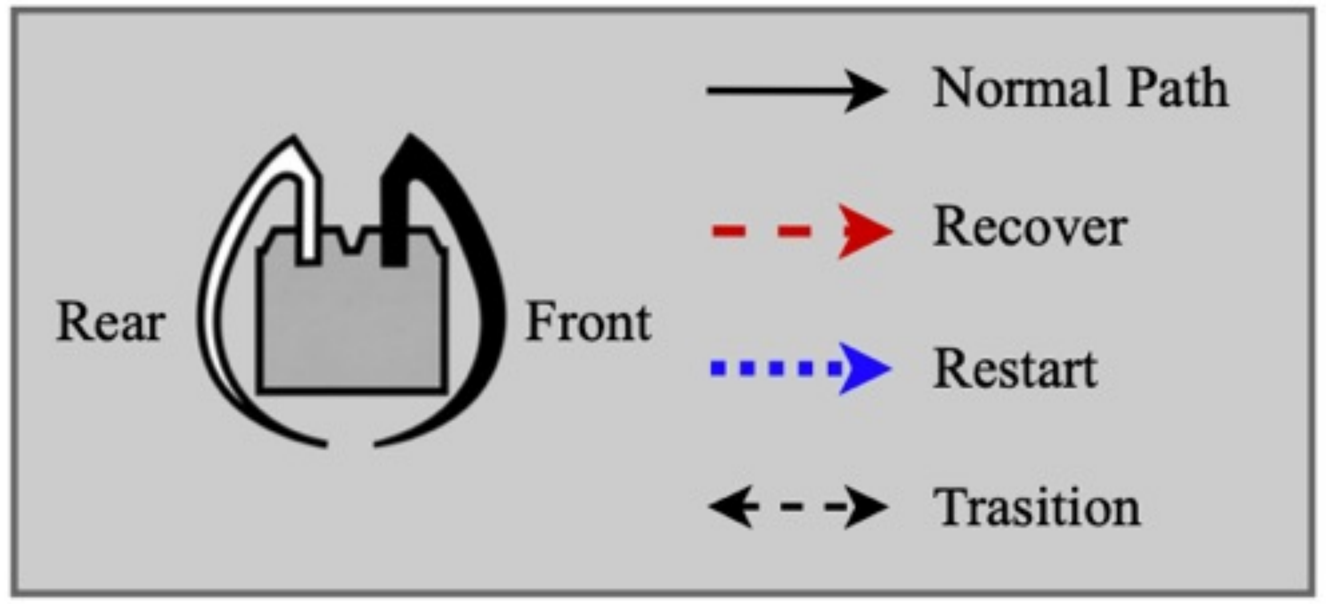
Contour plot for J1 (gravitational contribution), as a function of body and leg angles; darker region favors to CW rolling

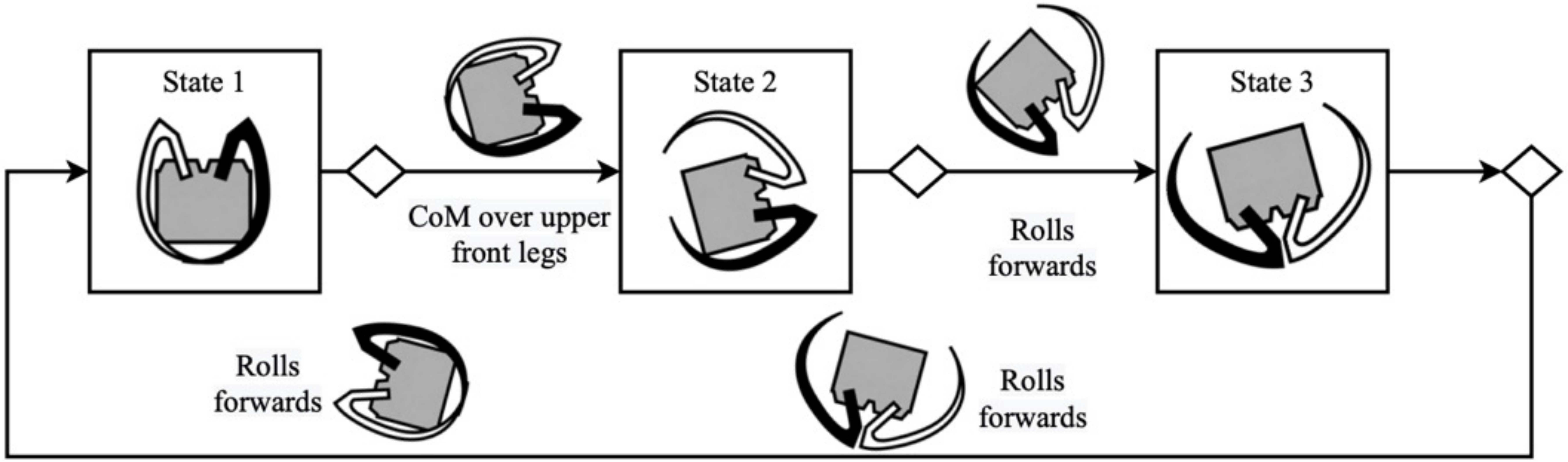


Rolling sequences are discretized into three states

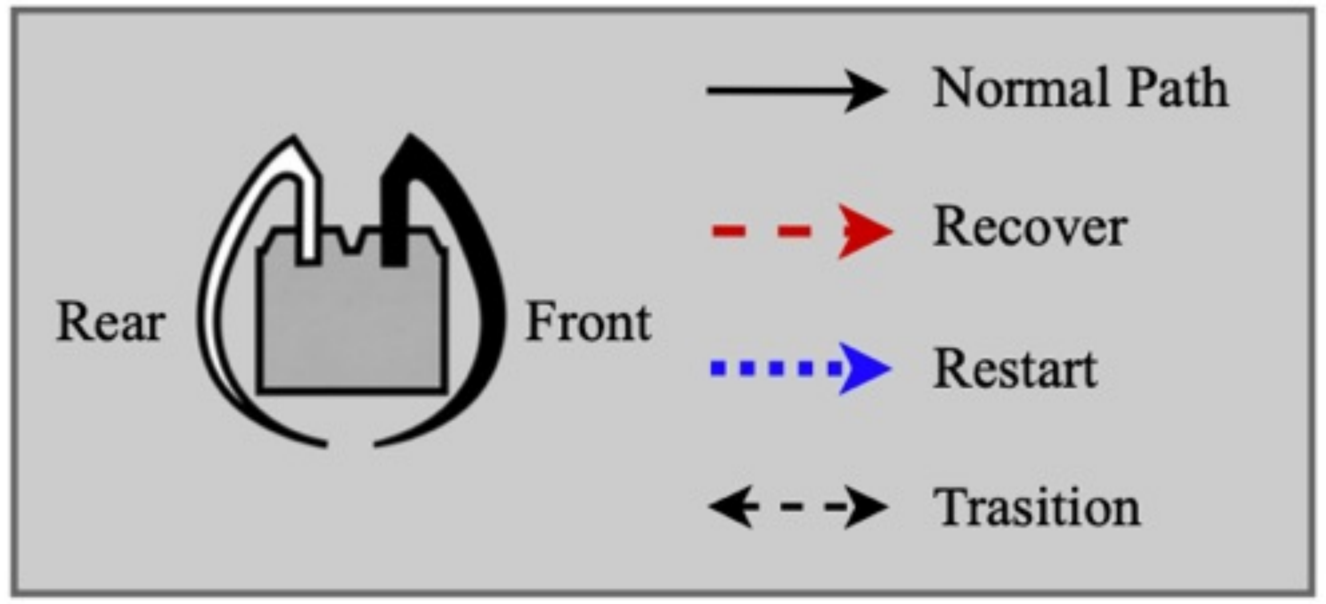


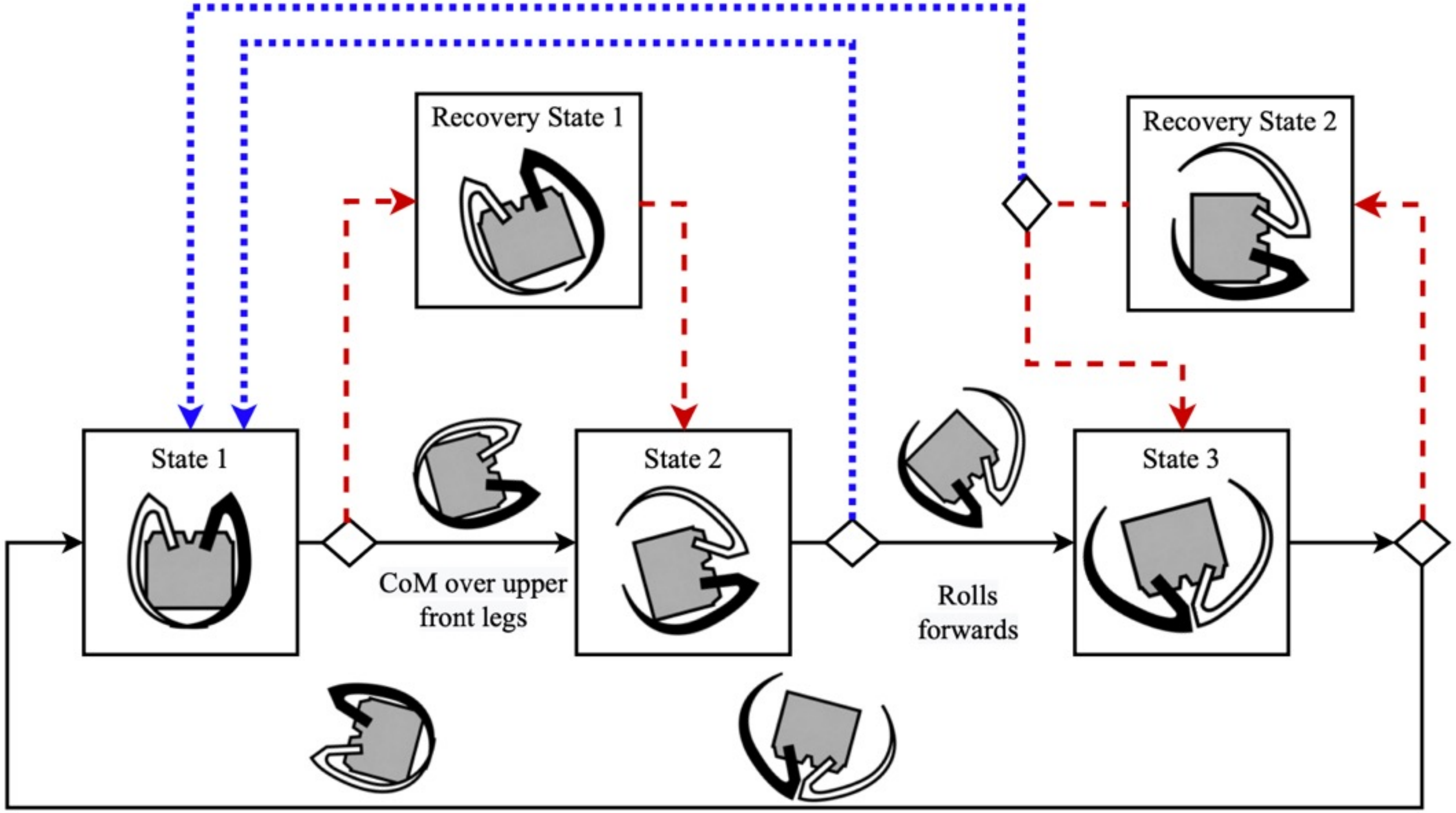
We simply follow the states in the contour plot to implement the event-driven controller of robot rolling



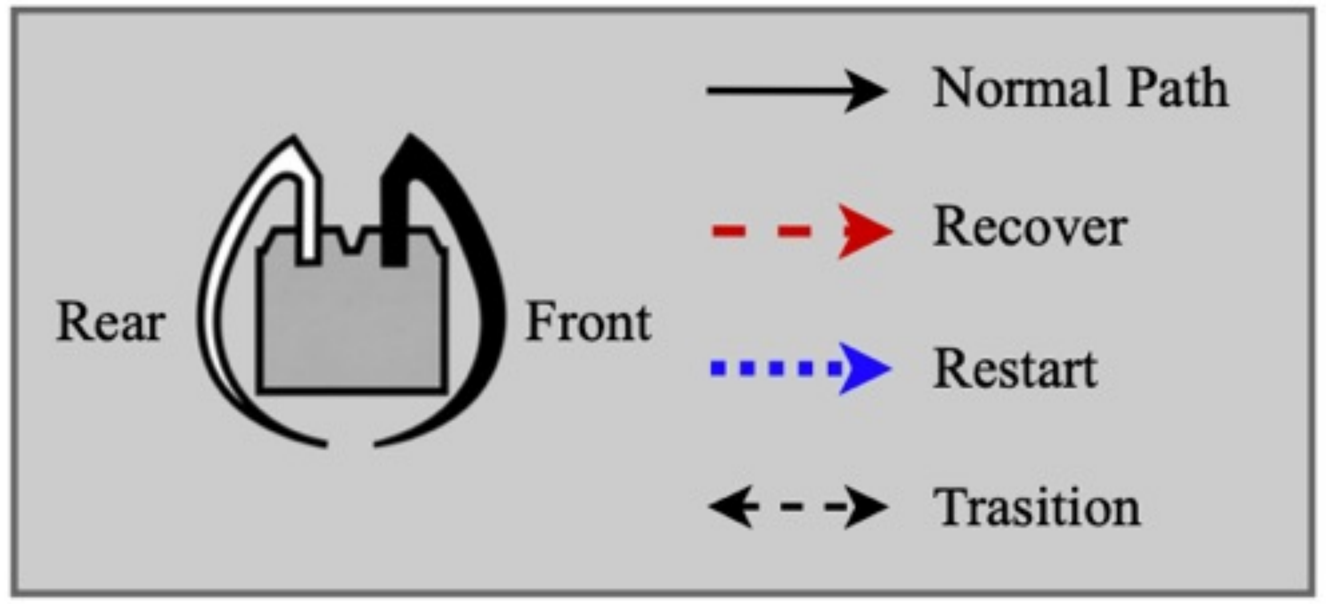


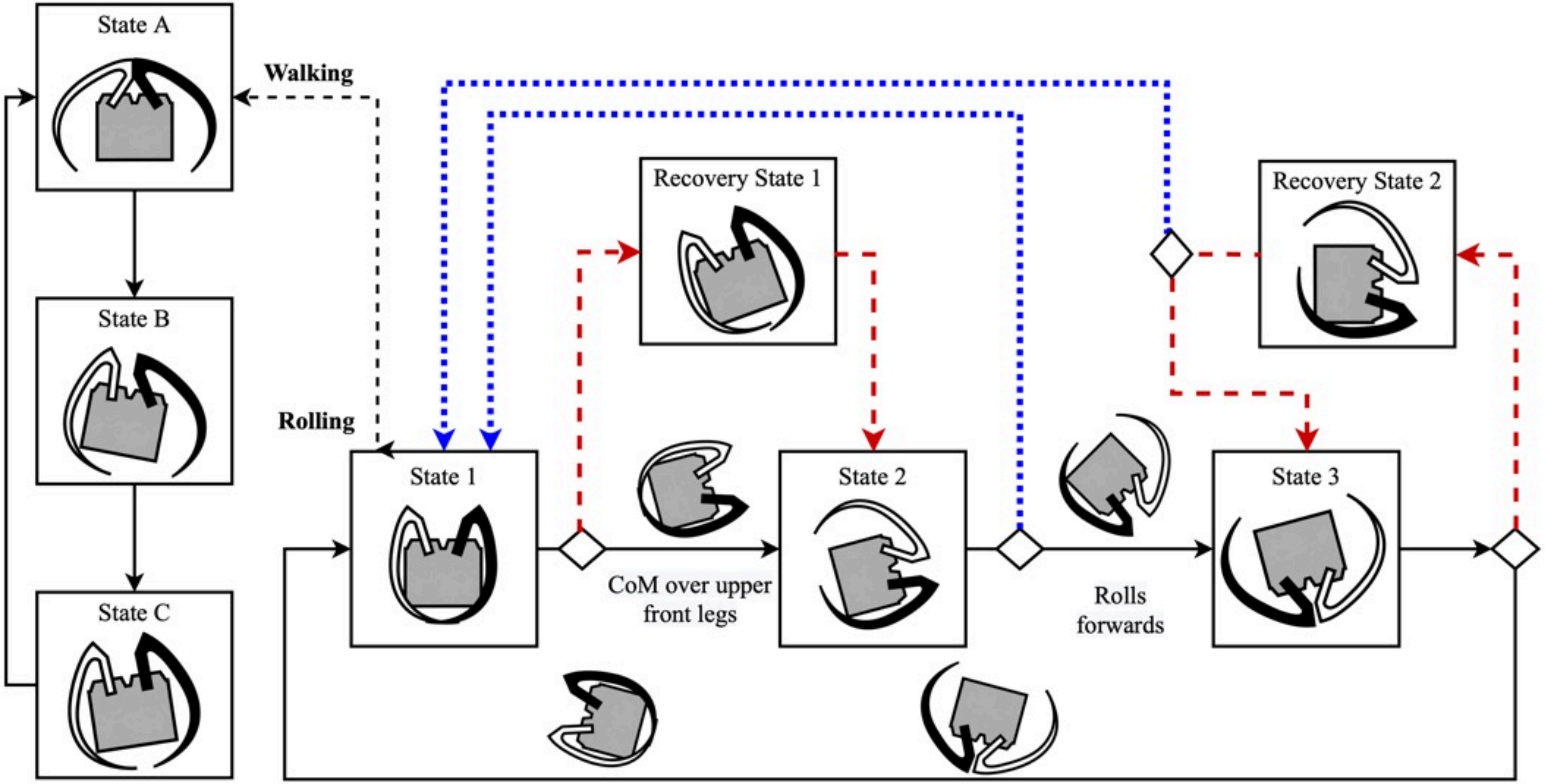
Two recovery states were designed by trial-and-error for situations where the robot does not complete the normal rolling steps





Walking control sequence is inspired by inchworm locomotion





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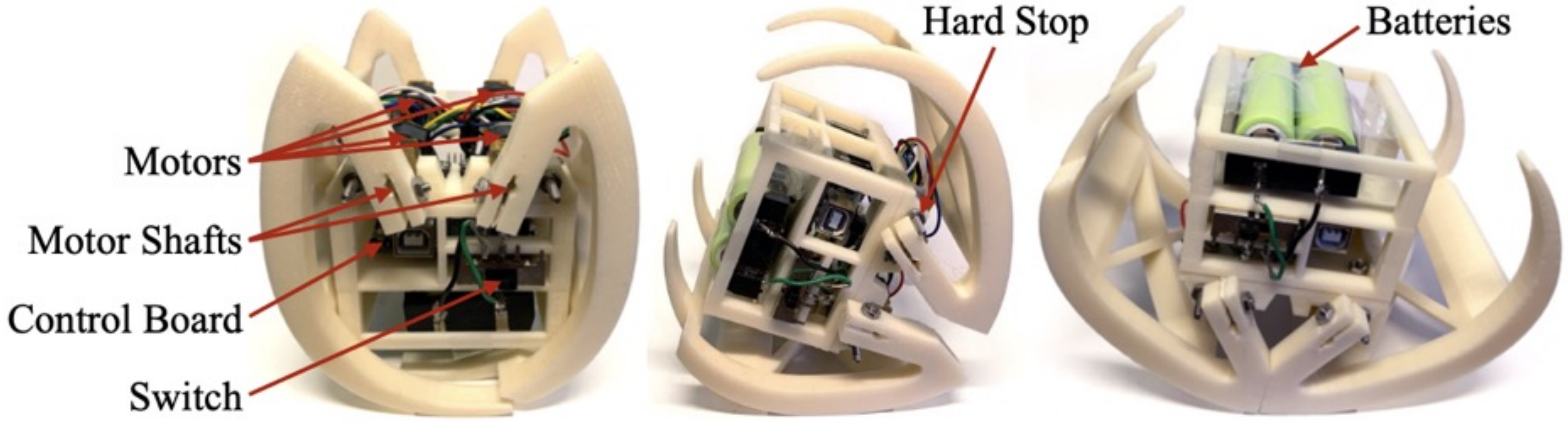
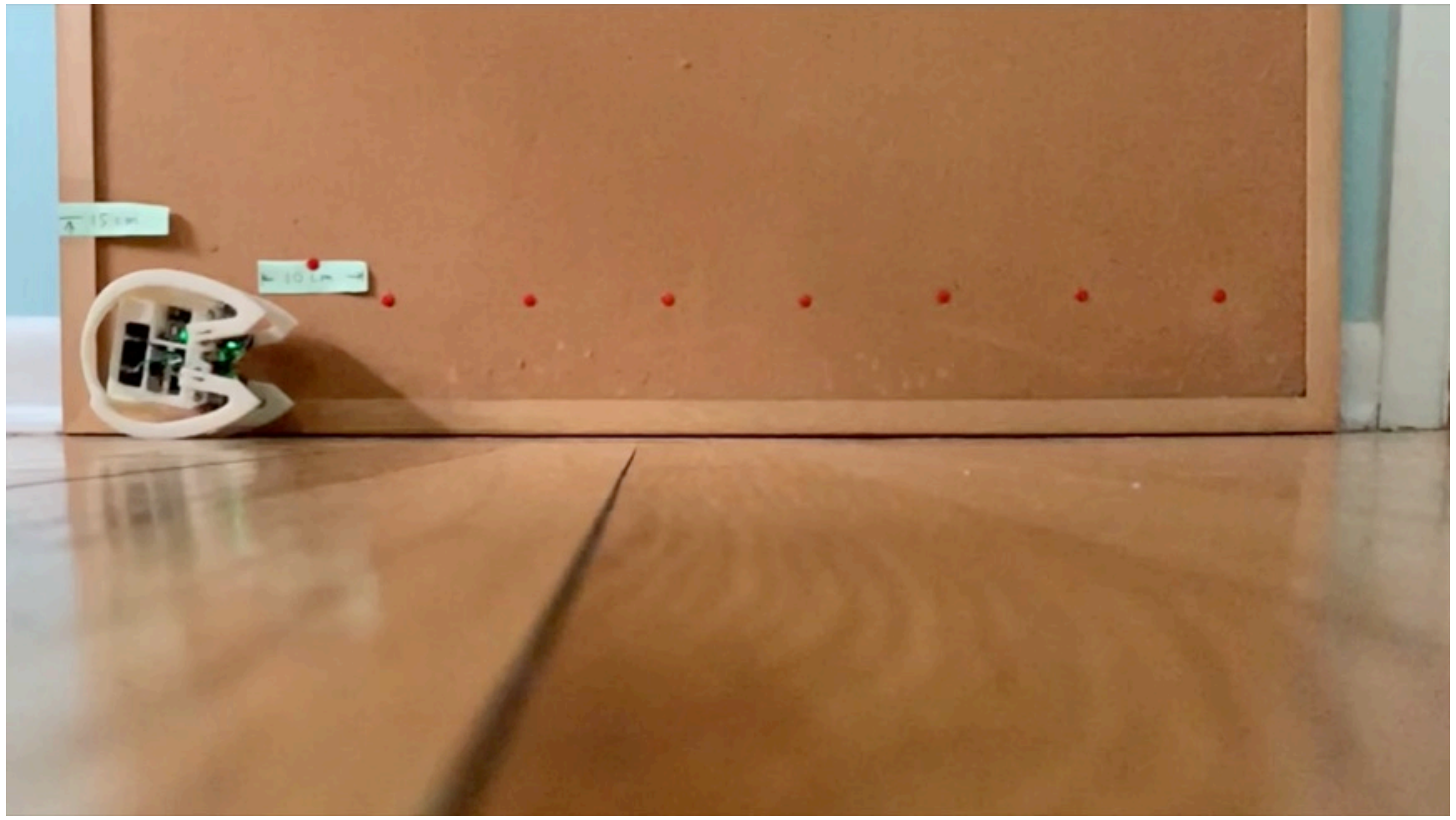
Prototyping

- 3D print chassis and legs
- Four geared motors, two DoFs
- CoM adjusted by battery pack position
- Arduino Uno microcontroller
  - Local PID motor control
  - Event-driven gait control
  - PWM control commands

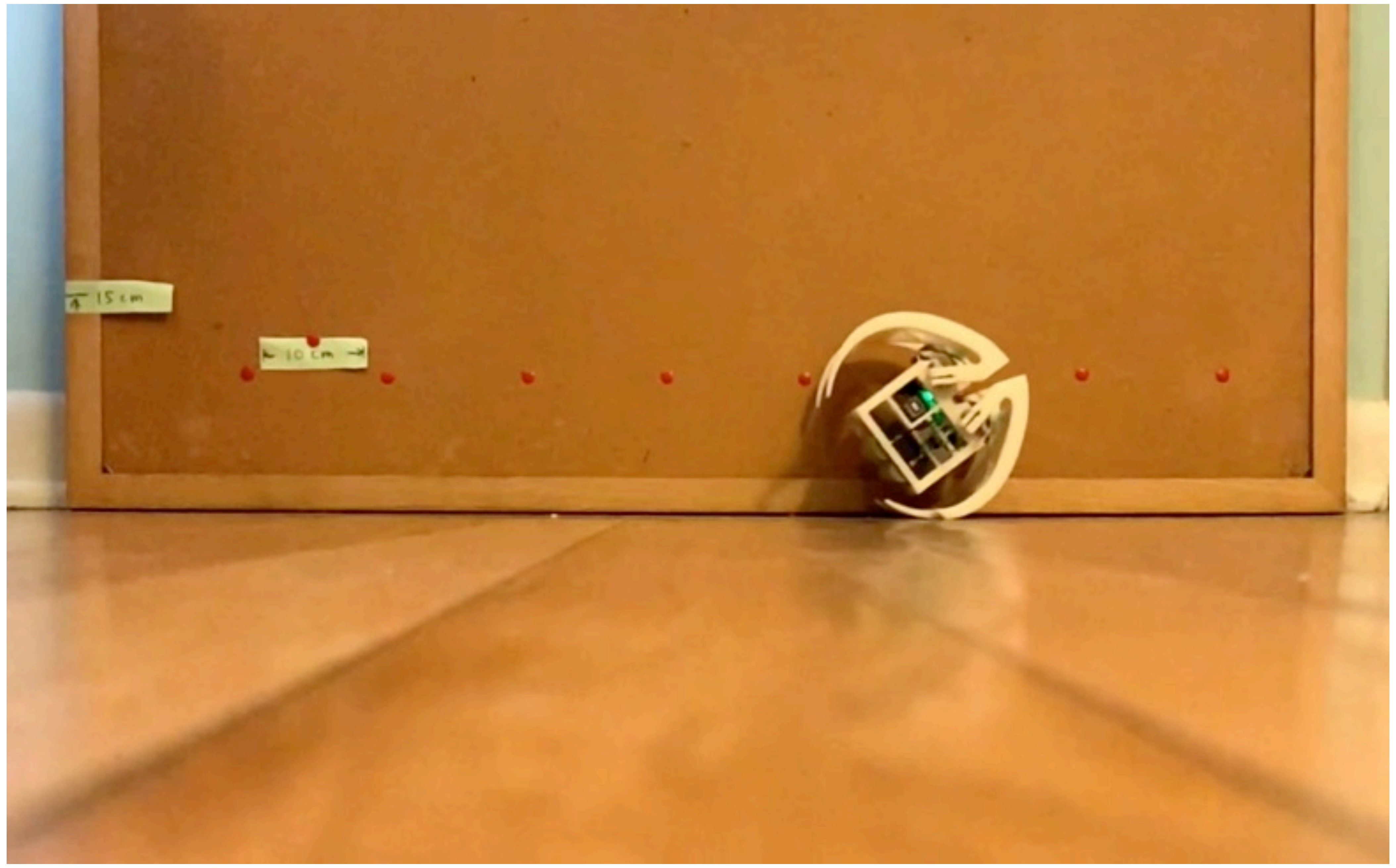


Videos

Rolling

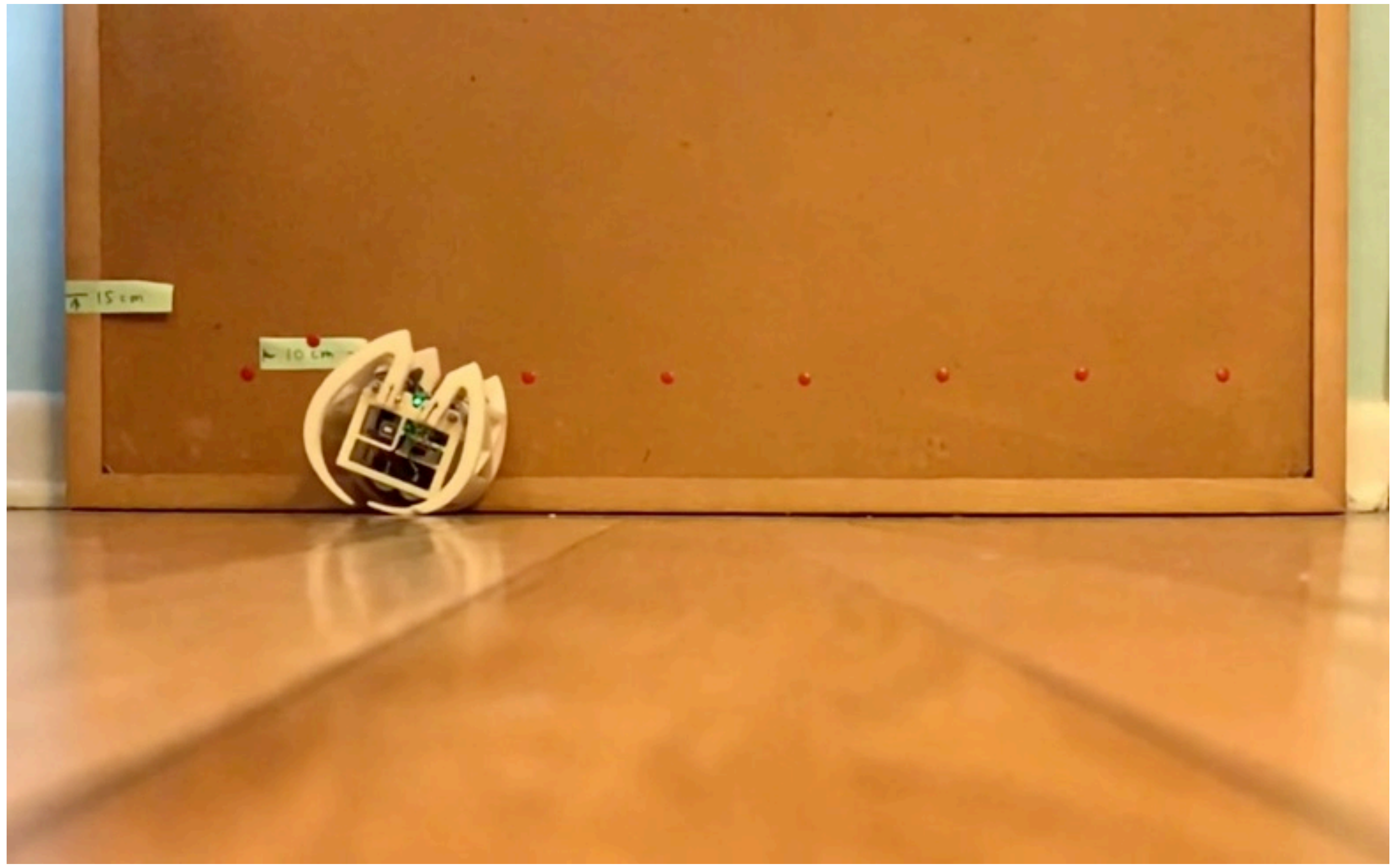


Walking and Transition



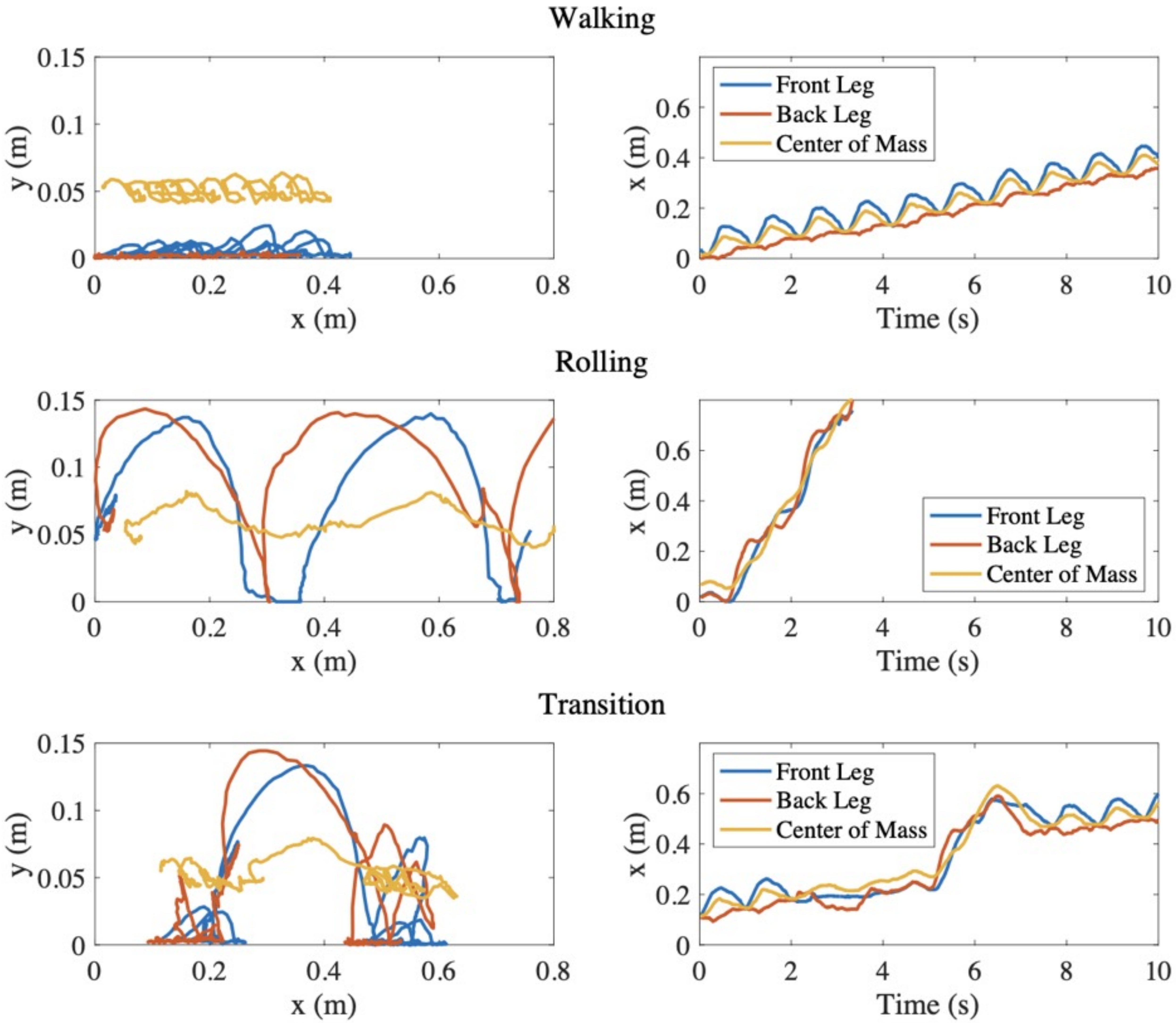
Videos

Recovery State 1



Recovery State 2

Rolling is much more efficient than walking based on the plots of COM and leg tips



Lowest cost-of-transport in rolling among similarly-scaled robots*

Walking: 0.038 m/s, 0.67 watts, 4.62 CoT

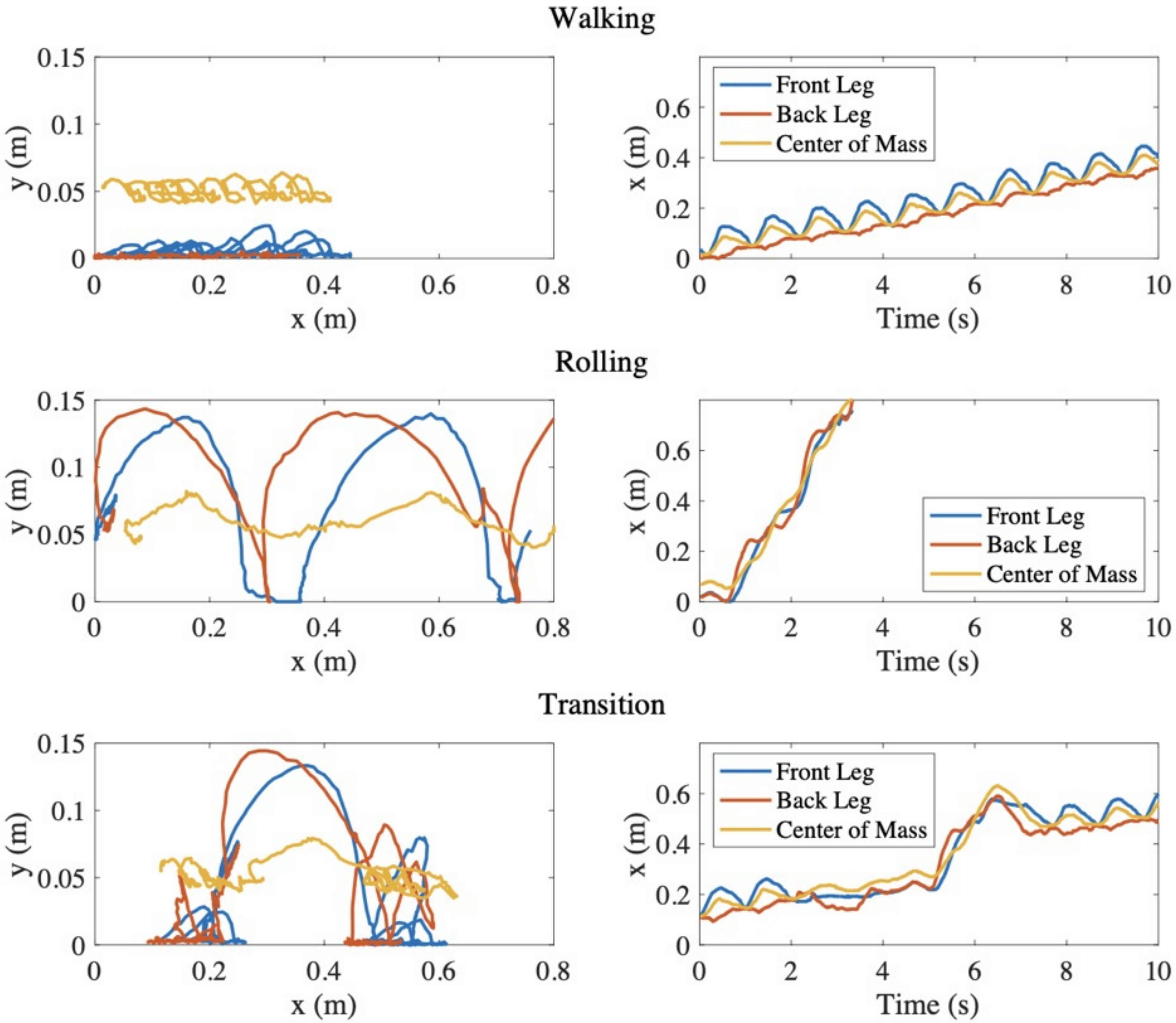
Rolling: 0.24 m/s, 0.46 watts, 0.52 CoT

energy, duty cycle, velocity, sampling period, motor stall current

$$E_i = \sum (dVi_{max}T) \quad (4)$$

cost-of-transport, distance

$$CoT = \frac{\sum_{i=1}^{4} E_i}{mgD} \quad (5)$$



*compared to similarly-scaled robots that have enough data reported in literature. See more details in our paper.

Conclusions

- Closed-loop multi-modal walking/rolling motion with just 2 DoFs and finite joint range of motion
- Novel leg geometry design process that provides guidance to controller design
- Competitive speed and lowest cost-of-transport (rolling), good cost-of-transport (walking) among similarly-scaled robots
- A template for further miniaturization of multi-modal mobile robots

Thank You!
Any questions?

dkguo.com/walk2roll