EXPERIMENTAL DEMONSTRATION OF FORCE CONTROL IN SPRING-MASS HOPPING

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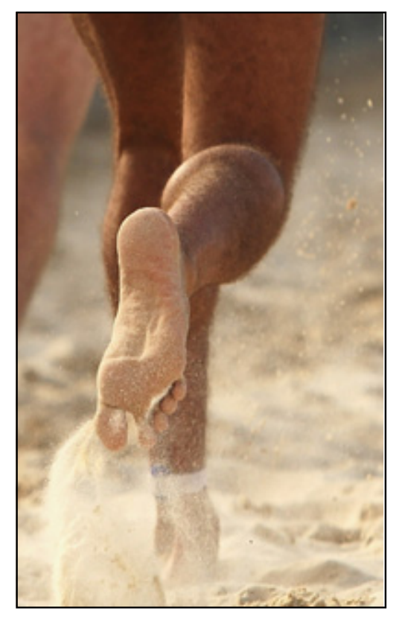
Goal



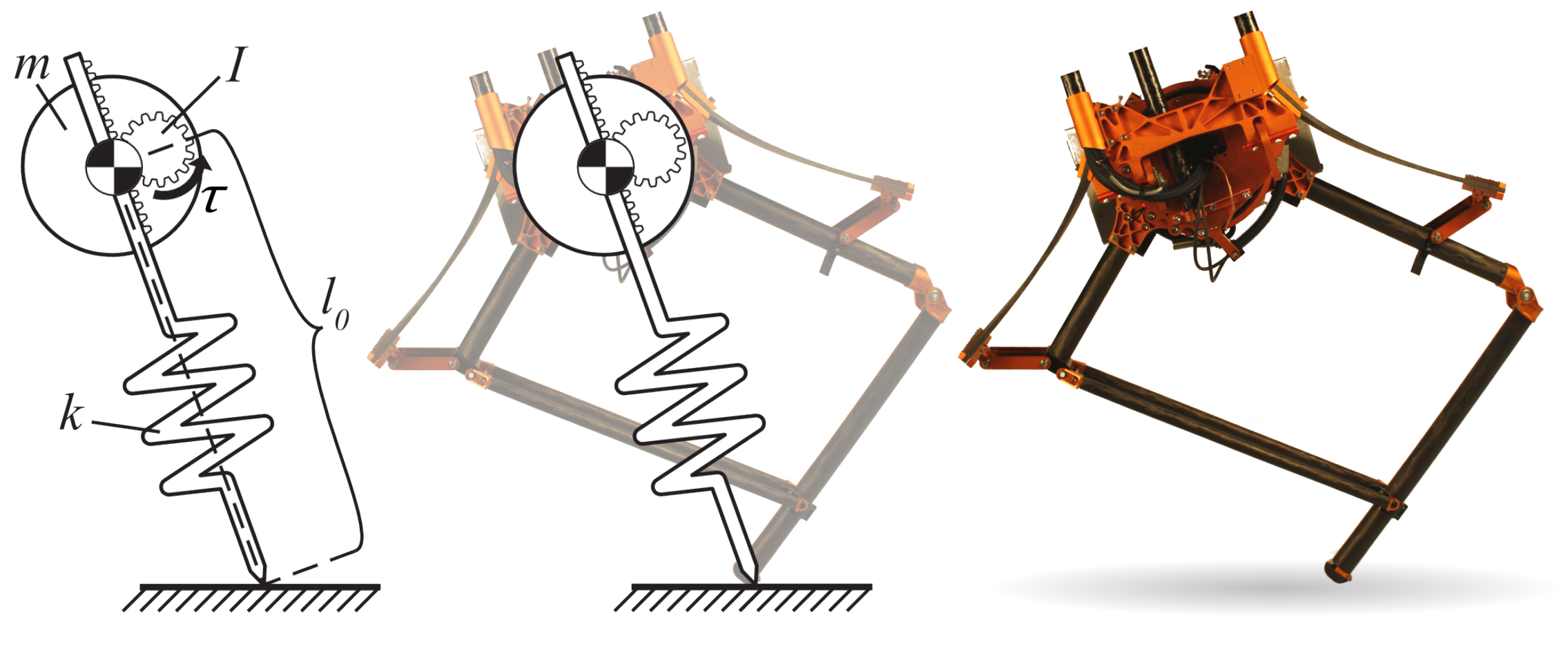
Our goal is to enable robots to hop, and ultimately run, on *unknown terrain impedance* such as sand, soil, and snow.

We seek a controller for maintaining steady-state *spring-mass hopping*:

- Rejecting any **nonrigid terrain** in one step, marked by a steady **apex height**
- With **no knowledge** of ground properties
- With **no feedback** from world coordinates or inertial measurement
- Using **minimum energy cost**

ATRIAS 2.0: Spring-Mass Monopod

Robot experiments were performed on the spring-mass, model-based monopod, *ATRIAS 2.0*



Spring-Mass Model ***ATRIAS 2.0***

References

[1] Blickhan R Ernst M. Geyer H. Spring-legged locomotion on uneven ground: a control approach to keep the running speed constant. *Proc 12th Int Conf on Climbing and Walking Robots (CLAWAR)*, pages 639–644, 2009.

[2] Christian M Hubicki and Jonathan W Hurst. Running on soft ground: simple, energy-optimal disturbance rejection. In *Proc 15th Int Conf on Climbing and Walking Robots (CLAWAR)*, volume (accepted), page (accepted), 2012.

[3] Devin Koepl and Jonathan Hurst. Force control for planar spring-mass running. In *Intelligent Robots and Systems (IROS)*, pages 3758 –3763, sept. 2011.

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Acknowledgements

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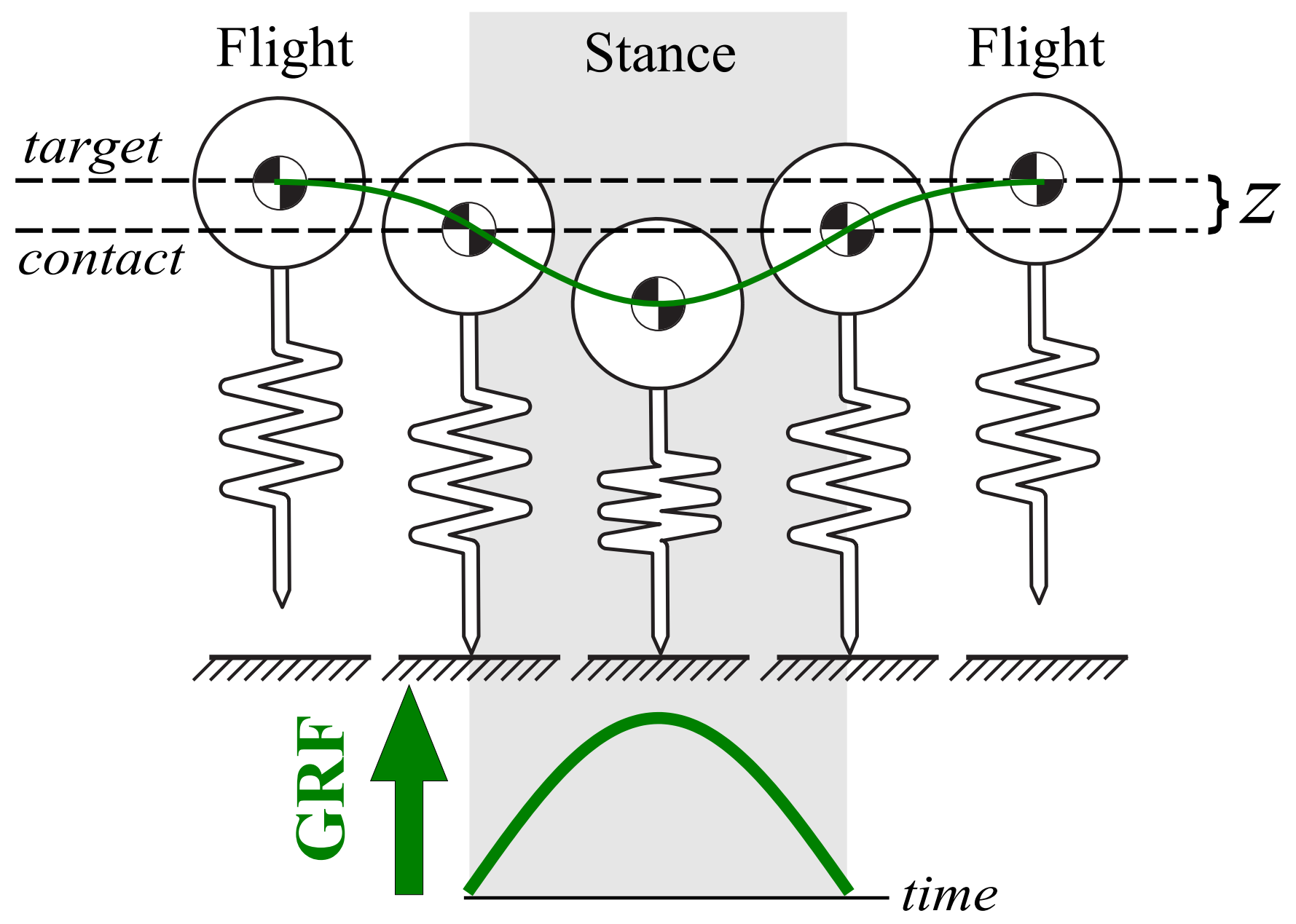
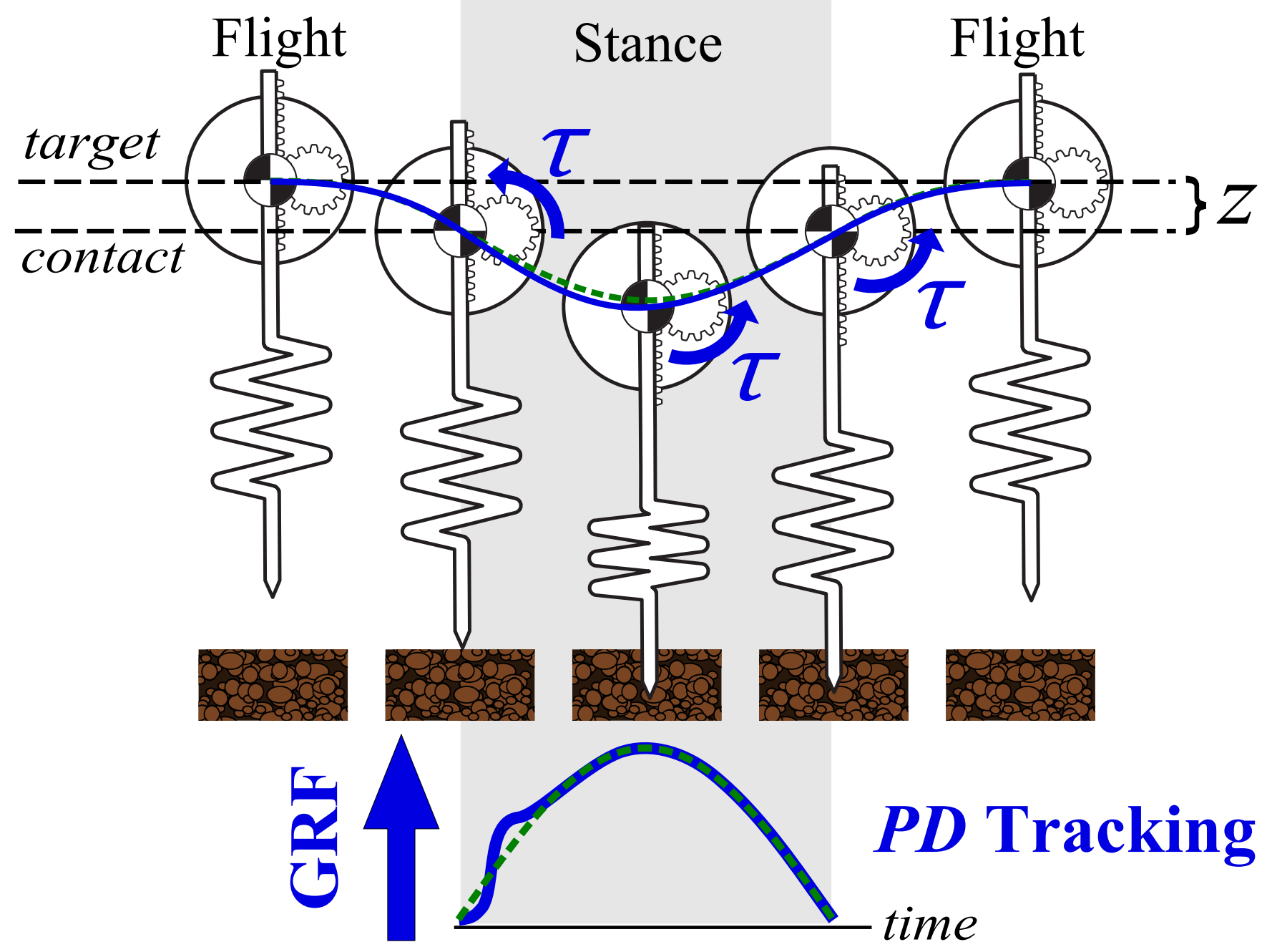
Force Controlled Hopping

"Force control" accomodates nonrigid terrain by regulating the ground-reaction forces to mimic rigid terrain.

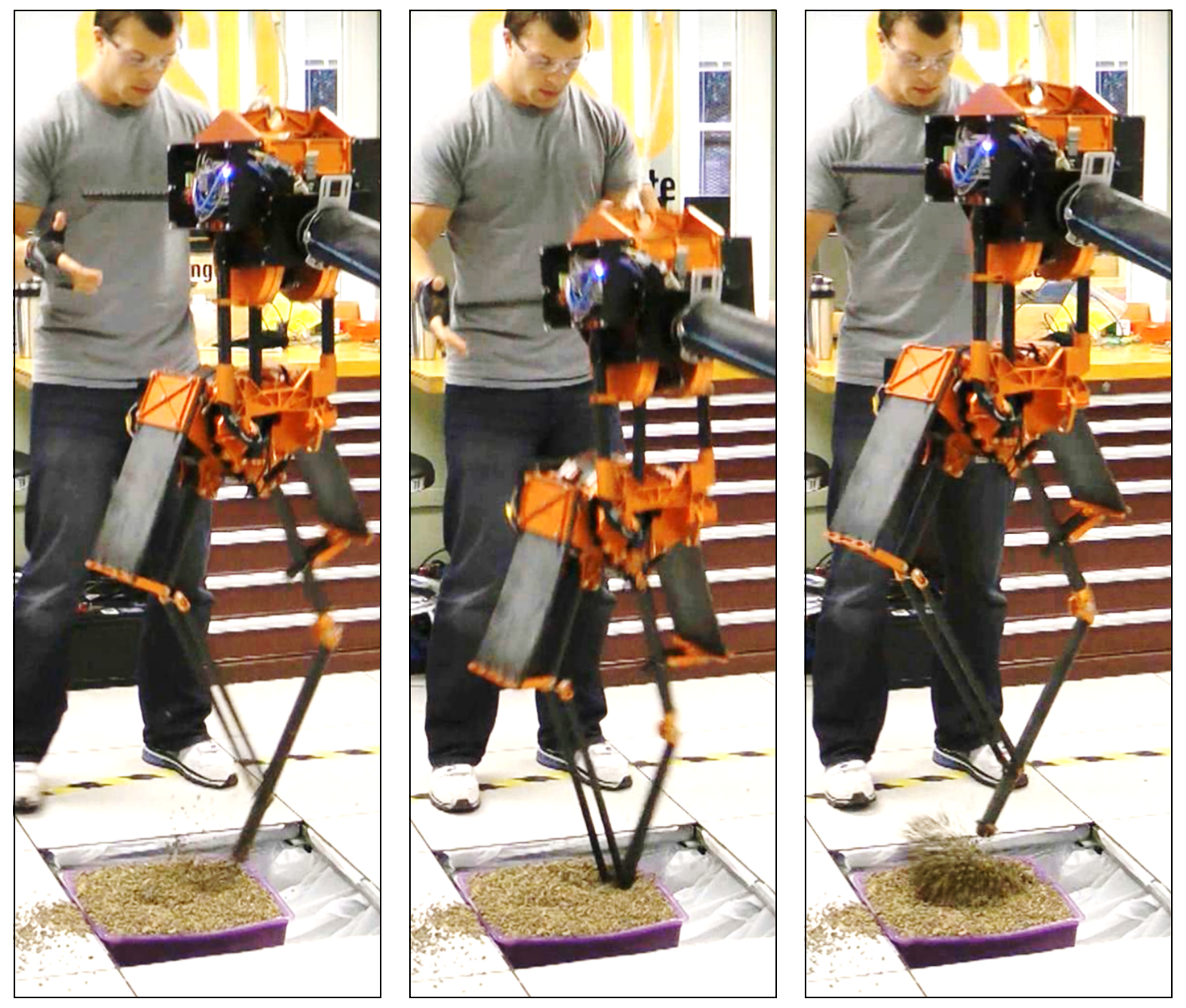
Ideal "Passive" Stance Phase



Force Control Tracking "Ideal" Stance Forces



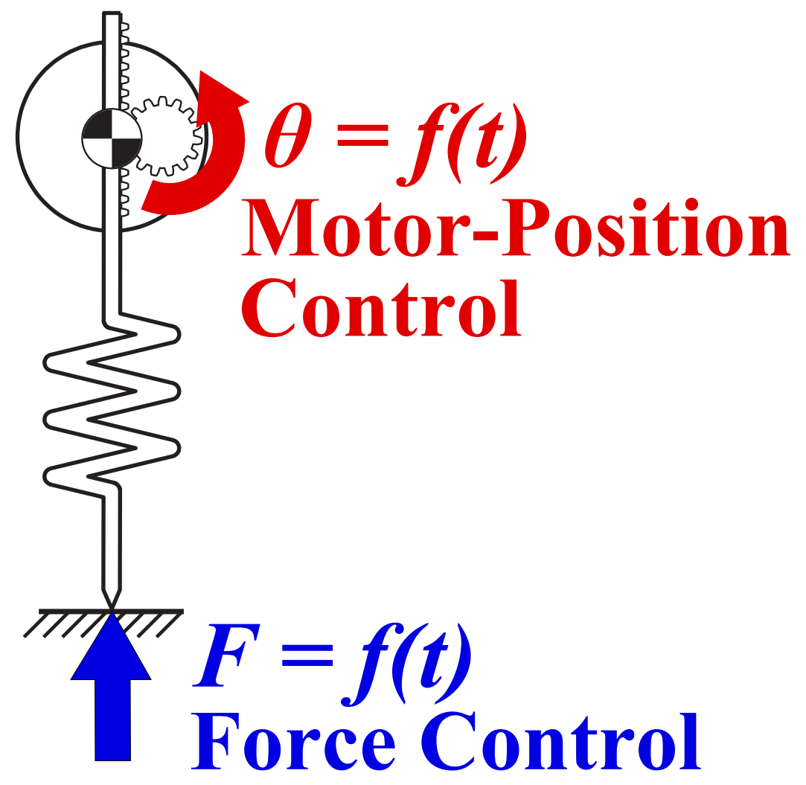
Demonstration: "Extreme" Case



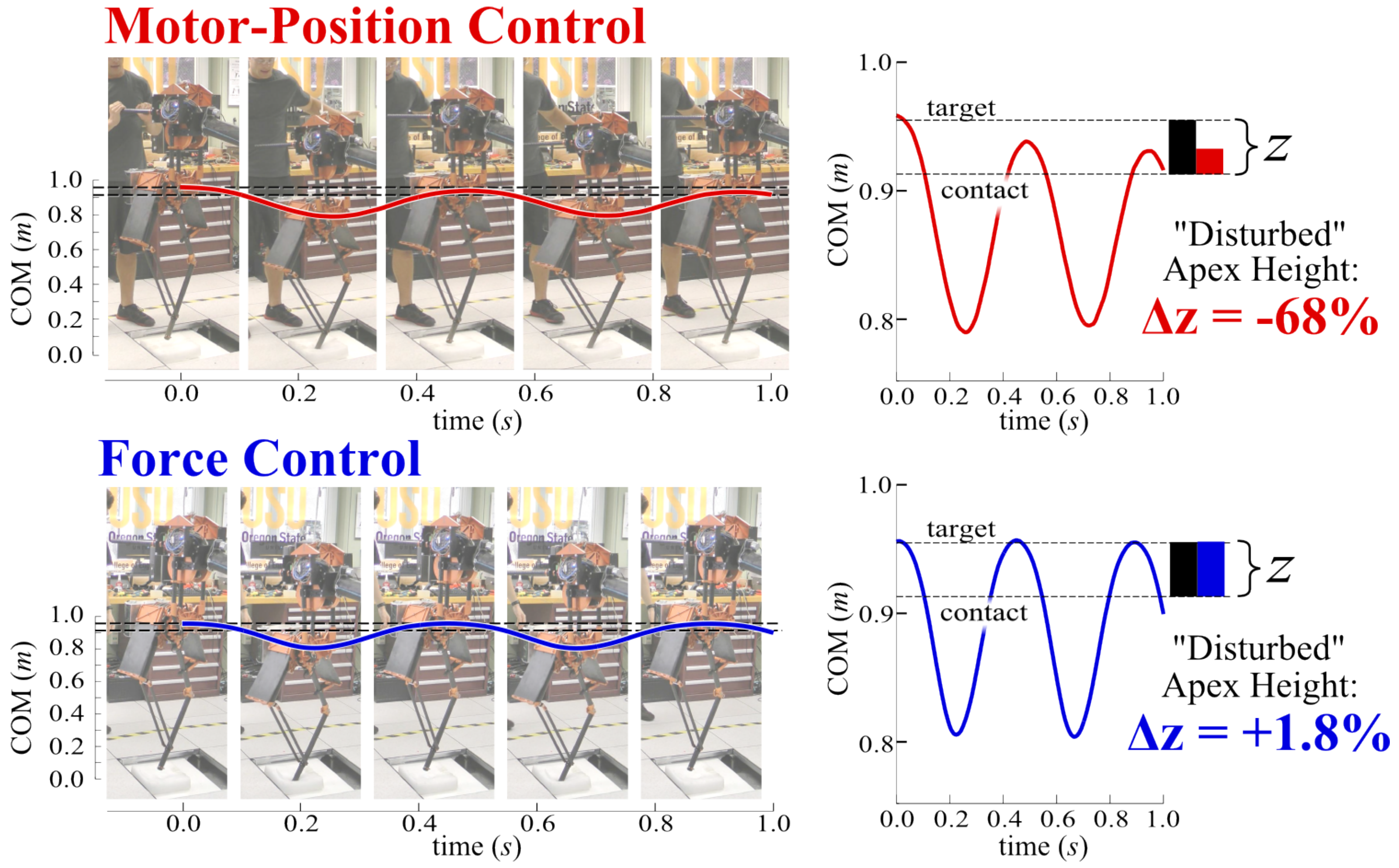
"Force control" negotiating a 6.5-inch plunge into an unseen gravel pit with only proprioceptive feedback

Comparable Controllers

- Force Control tracks ground-reaction forces
- Motor-Position Control tracks rotor trajectory of force control on rigid ground



Robot Experiment



While motor-position control loses 68% of its hop height on soft foam, force control maintains its apex height without sensing it

Force Control vs. Motor-Position Control:

Both force control and motor-position control perform identically on rigid ground. On dissipative surfaces, force control should add the necessary energy to maintain hopping height.

Experiment:

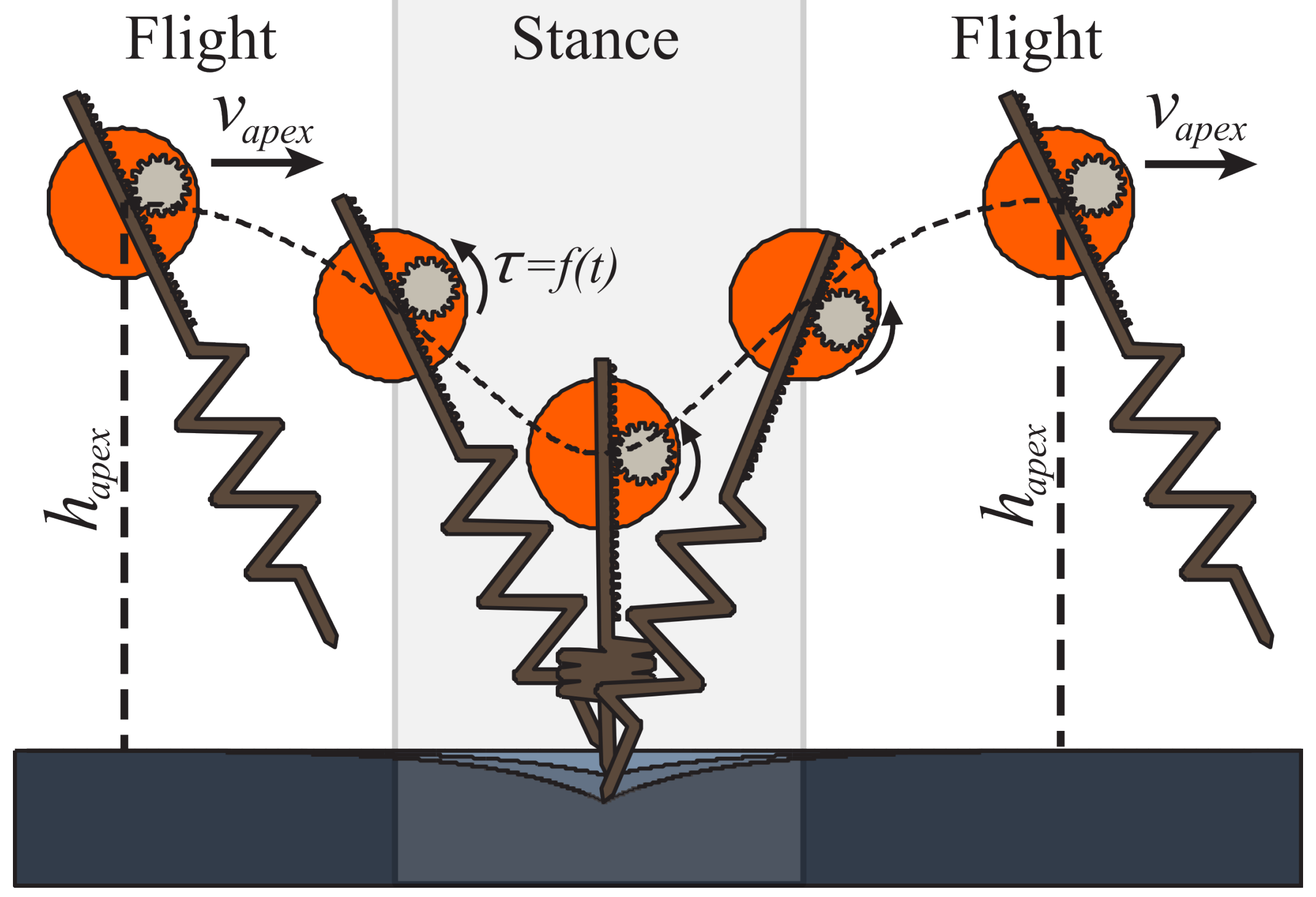
The monopod was dropped on thick, soft foam with no changes to the controllers. Force control recovered completely within a single hop, maintaining the original target apex height. Motor-position control, however, quickly lost energy and, consequently, apex height.

Extensions to Running

"Force control" extends easily into running

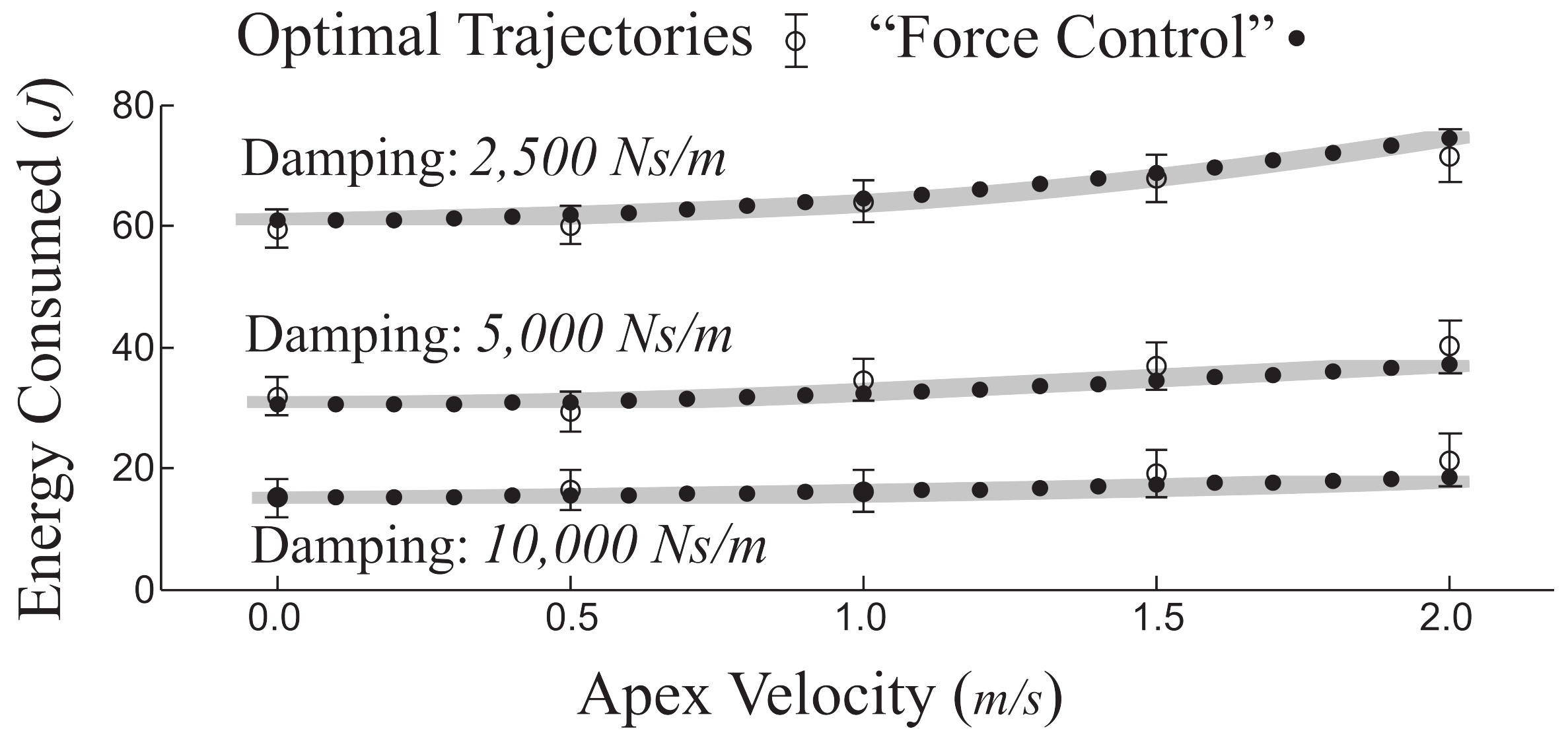
- Flight phase control produces equilibrium gaits [1]
- Force control maintains equilibrium gait on soft ground [3]

Equilibrium Gait: Constant v_{apex} and h_{apex}



Energy-Optimal Recovery

"Force control" yields identical energy cost to optimal trajectories on dissipative terrain [2]



Conclusions

Force control for spring-mass hopping:

- **Immediately recovers** from various nonrigid surfaces while comparable controllers fail to maintain steady-state hopping
- Requires **no estimates** of the ground impedance and only priopriocептive feedback
- Facilitates **energy optimal** recovery from dissipative surfaces