Learning to Walk – Optimal Gait Synthesis and Online Learning for Terrain-Aware Legged Locomotion

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CPS Goal

Advance CPS by more explicitly tying sensing, perception, and computing to the optimization and control of physical systems with variable and uncertain properties.

Research Goal

Improve the perception and control of legged locomotion over granular media for the express purpose of achieving robust, adaptive, terrain-aware legged locomotion.

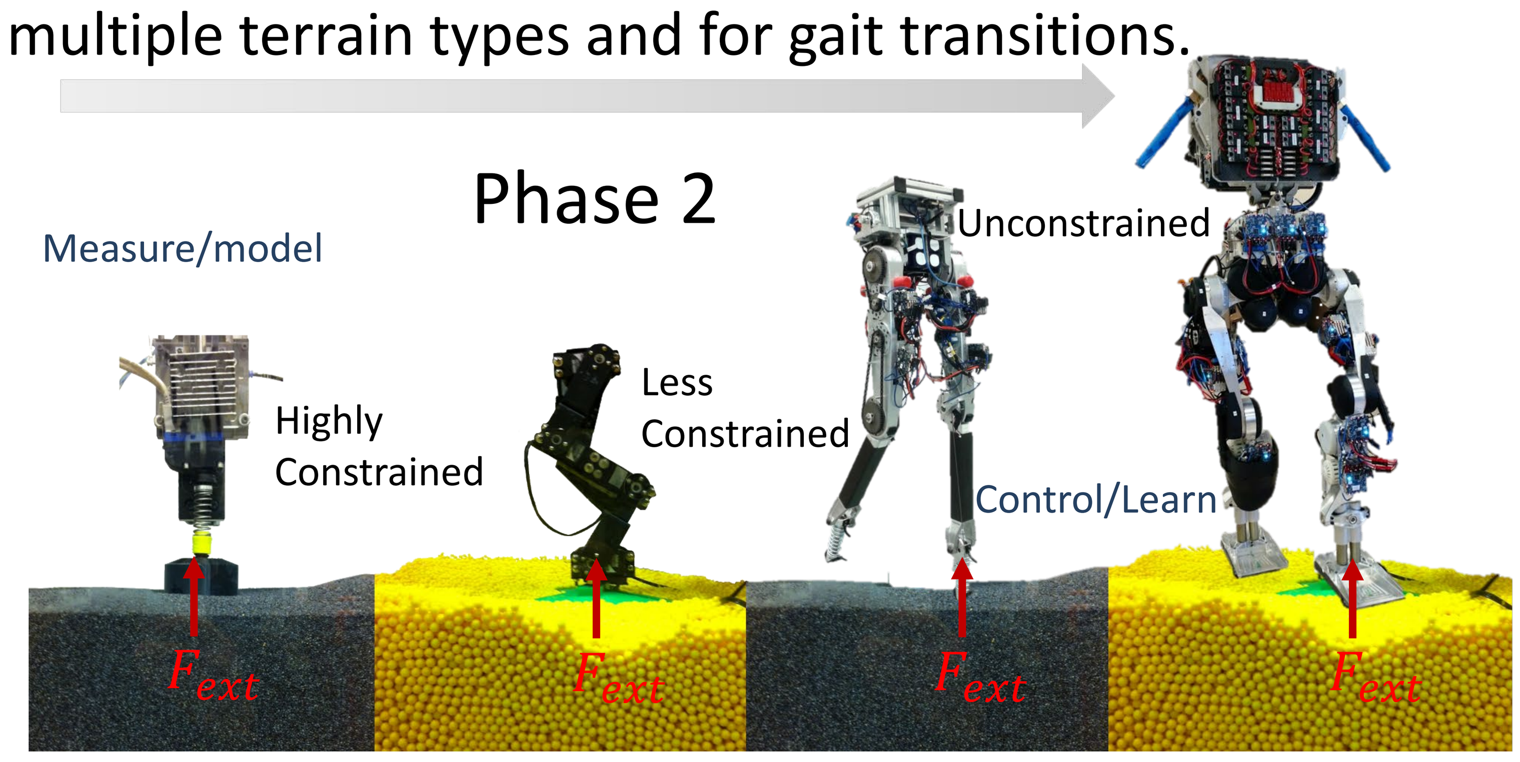
Objectives

- Validated co-simulation platform for legged robot movement over granular media;
- Terrain-dependent, stabile gait generation and gait transition strategies via optimal control;
- Online, compute-constrained learning of granular interactions for adaptation and terrain classifications; and
- Validated contributions using experimental, granular-media testbeds
- Communicate value of STEM education.

Task2: Derive dynamics and gait controller,

$$\dot{x} = f\big(x(t), u(t)\big) + g_{ext}(x(t))\, F_{ext}$$

for multiple terrain types and for gait transitions.



Task 1: Experimentally derive granular force laws for modeling F_{ext} through controlled experiments.

Task 3: Learn terrain models (F_{ext}) online. Classify terrain based on experienced models.

Task 4: Integrate and validate research contributions.

Scientific Value

- Uncertain dynamics and external forces/disturbances are common to all controlled systems.
- Research defines, proves, and validates a process for integrating learning and adaptation for improving close loop performance and fidelity of trajectory synthesis during task execution.

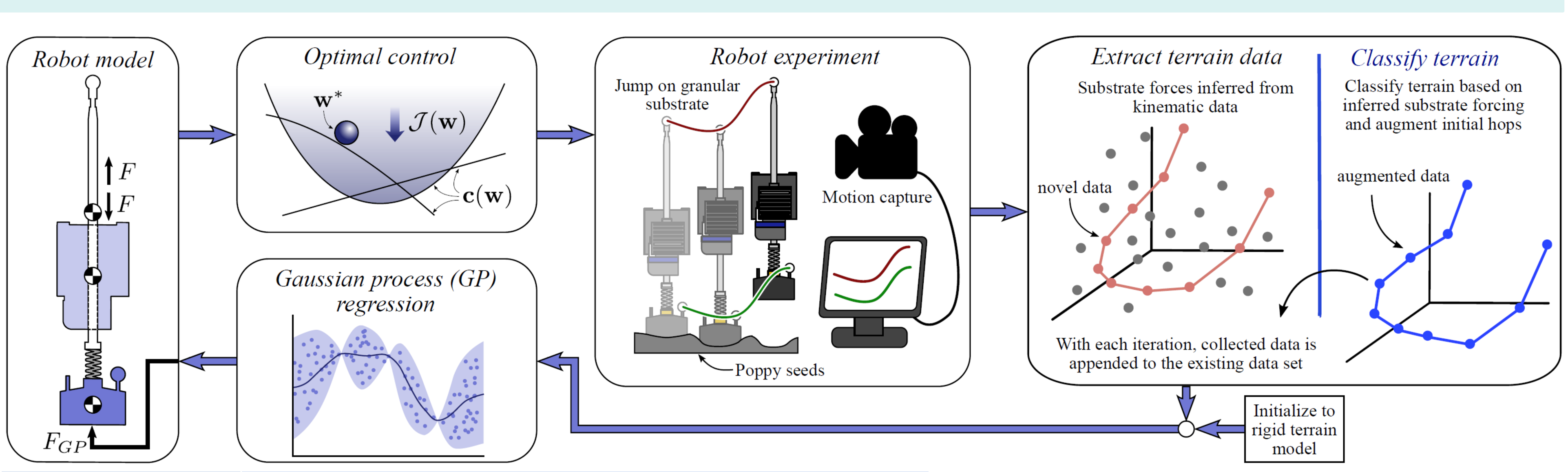
Broader Impacts

- Enhances and improves robustness of robotic and control systems so that real-world operation possible. Large class of automated systems with societal benefit impacted.
- Robotic platforms used to promote and attract youth to engineering.

Online Classification, Knowledge Transfer, and Learning of Terrain Forces

Objective: Enhanced Operation and Learning Through Memory of Learnt Models.

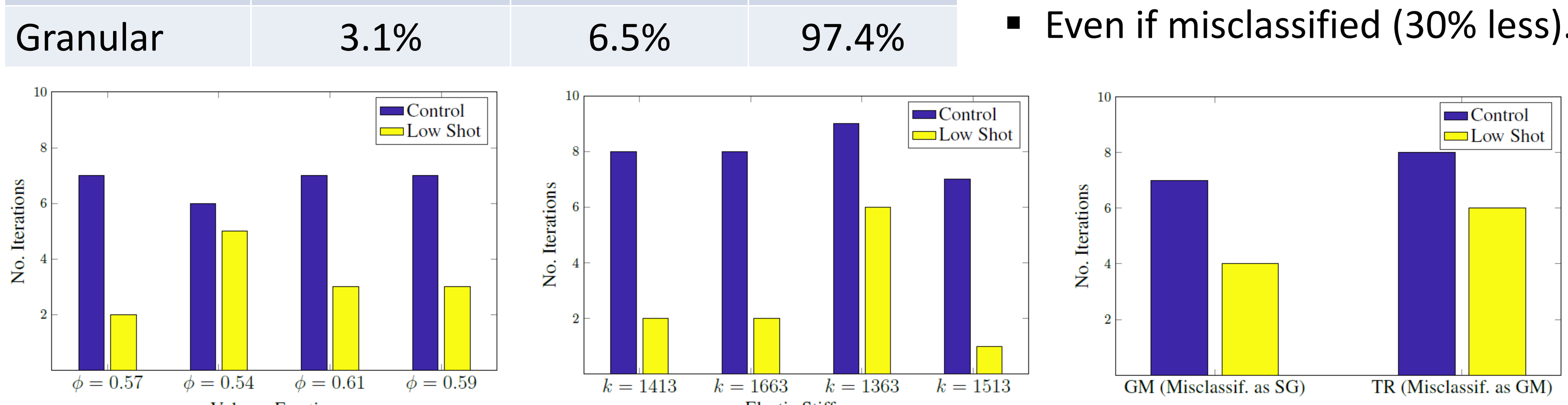
- Start with general models from prior experiences with different terrain.
- Classify *new* terrain experience using models from prior experiences.
- Employ prior knowledge within learning process



Prediction	Ground Truth		
	Solid Ground	Trampoline	Granular
Solid ground	96.9%	0.7%	2.6%
Trampoline	0.0%	92.8%	0%
Granular	3.1%	6.5%	97.4%

Outcomes:

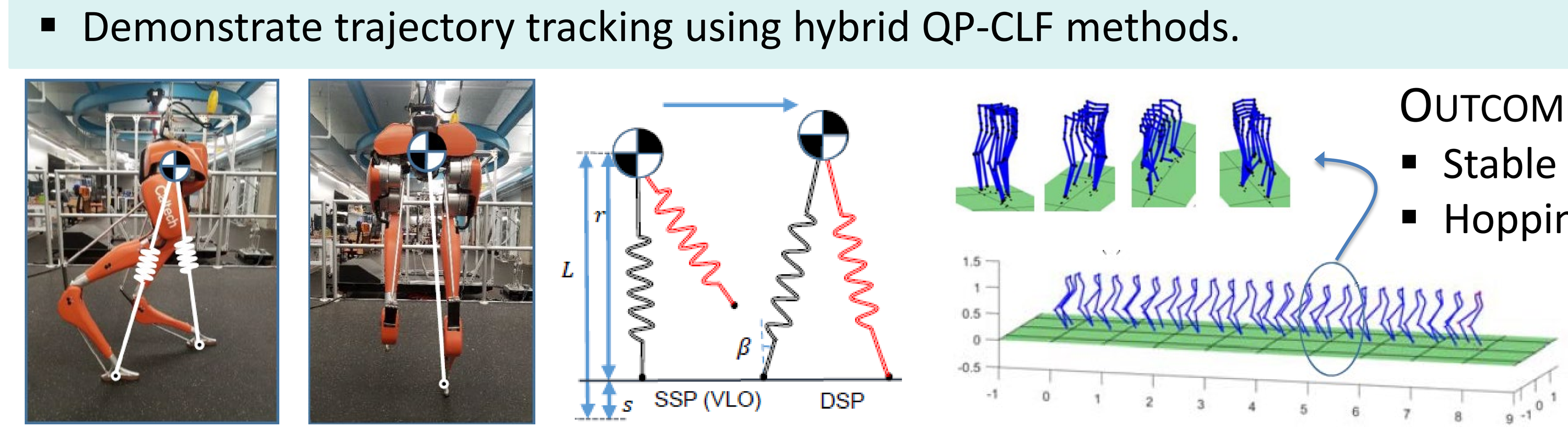
- High classification rate (> 95%).
- Prior knowledge enhances learning (50% or less hops).
- Even if misclassified (30% less).



Gait Synthesis for Walking with Complex Legged Robots

Objective: Apply Concepts to New Robot Walker, Cassie.

- Employ reduced order model within numerical control and optimization routines.
- Map policies of reduced order model to original hybrid system.
- Demonstrate trajectory tracking using hybrid QP-CLF methods.



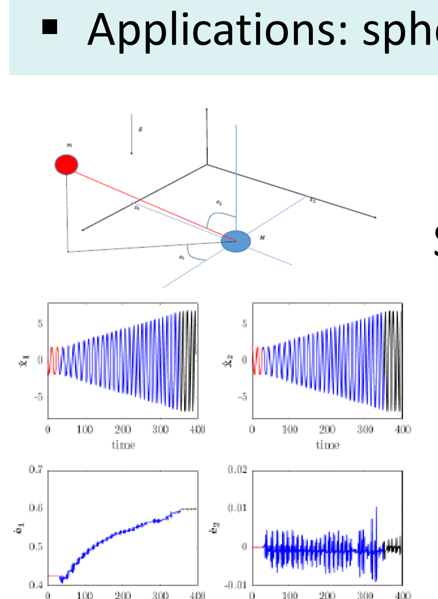
Outcome:

- Stable walking
- Hopping

Optimal Transitions between Orbits

Objective: Enlarge Scope of Raccordation Theory

- Graceful transitions for controlled systems involving tracking of stable orbits.
- Applications: spherical pendulum and fully-actuated walking



$$M(q)\ddot{q} + C(q,\dot{q})\dot{q} + G(q) = u$$

System w/reset map. $x^{+} = \Delta(x^{-})$

$$\min_{u(t,\alpha),T(\alpha)} \int_0^T L(q,\dot{q},\alpha)\,dt$$

Raccordation optimization