Walking on Rough Terrain with Any Number of Legs

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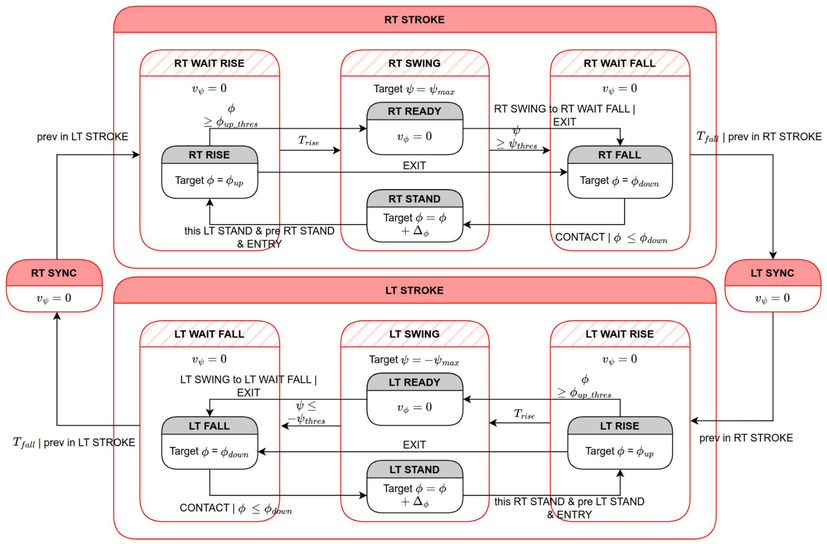
Project Background

Animals exhibit remarkable abilities to move efficiently through complex environments. Robotics would gain by replicating the agility of those arthropods. Early physiological studies on **central pattern generators (CPGs)** [1] established that animals possess neural circuits capable of producing rhythmic activity without requiring step-by-step sensory input, while **Walknet** [2] shows that stable insect gaits can emerge without strong central oscillators, relying instead on distributed sensory-driven coordination. In motor control research, bio-inspired CPGs, modeled as a system of coupled oscillators with each joint assigned an oscillator, have been broadly used for robots locomotion. Draw inspiration of both CPG and Walknet, we abstract the core functionality of CPGs into a small set of discrete, task-relevant states and implement using a **Finite State Machine (FSM).**

Controller and Robot Design

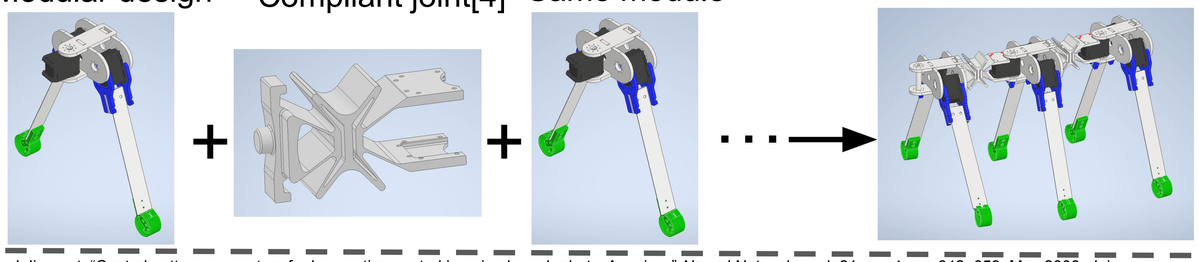
State Machine Diagram



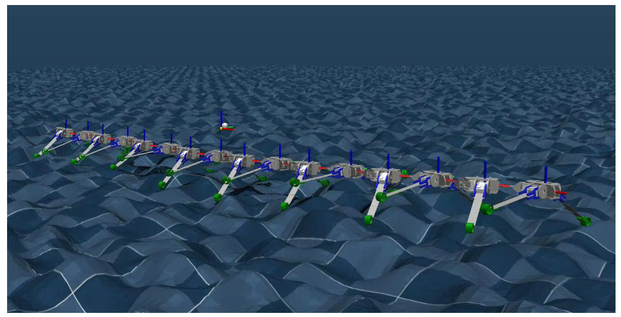
Yaw Machine: Control the overall rhythm of the robot

Leg Machine: Modulated by Yaw Machine and adapt to terrain height

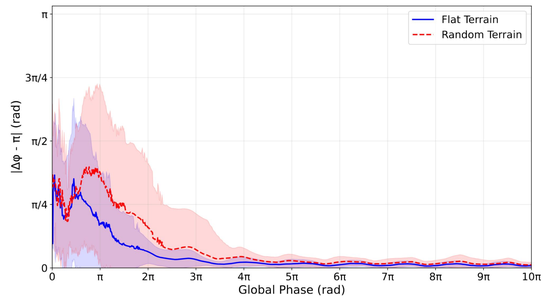
Modular design + Compliant joint[4] + Same module ⋯→ Whole Robot



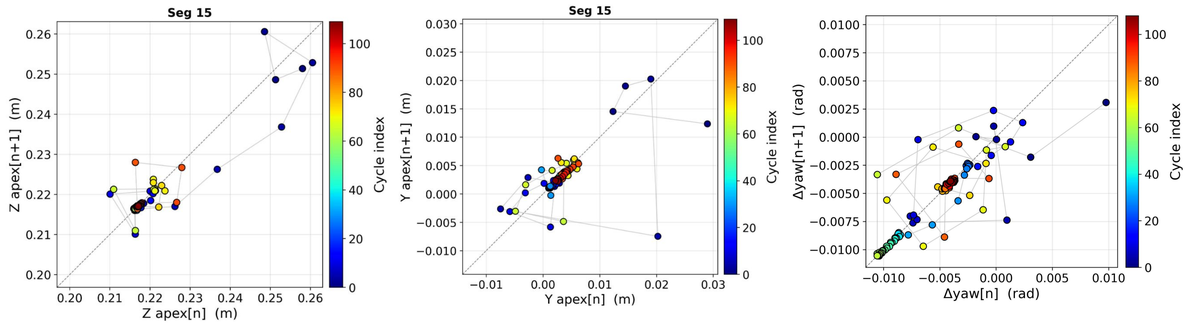
Simulation Experiments (From MuJoCo[3] Simulator)



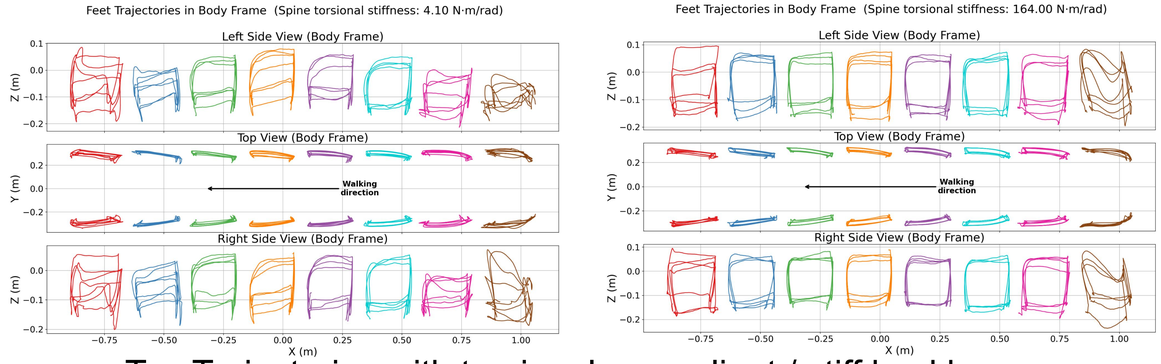
16-segment robot on rough terrain



Phase difference convergence



Apex Return Maps for 16-segment robot on flat terrain



Toe Trajectories with torsionaly compliant / stiff backbone

Discussion and Future Work

- All experiments were conducted in simulation, where both the physics and the robot models are simplified. Considerable work is still needed to develop a physical robot.
- The (XX)Z design for each segment reduces the number of motors required, but it also introduces slip. This slip has been shown to expand the kinematic workspace while preserving the essential nature of the motion.
- Scalability is demonstrated by increasing the number of simulated segments. However, a small disturbance at the front can grow significantly as it propagates to later segs..
- The FSM parameters are tuned manually. Learning-based adaptive tuning could further improve the robot's stability and adaptability.

[1] A. J. Ijspeert, "Central pattern generators for locomotion control in animals and robots: A review," *Neural Networks*, vol. 21, no. 4, pp. 642–653, May 2008, doi: https://doi.org/10.1016/j.neunet.2008.03.014.
[2] H. Cruse, T. Kindermann, M. Schumm, J. Dean, and J. Schmitz, "Walknet—a biologically inspired network to control six-legged walking," *Neural Networks*, vol. 11, no. 7–8, pp. 1435–1447, Oct. 1998, doi: https://doi.org/10.1016/s0893-6080(98)00067-7.
[3] E. Todorov, T. Erez and Y. Tassa, "MuJoCo: A physics engine for model-based control," *2012 IEEE/RSJ International Conference on Intelligent Robots and Systems*, Vilamoura-Algarve, Portugal, 2012, pp. 5026-5033, doi: 10.1109/IROS.2012.6386109.
[4] X. Pei, J. Yu, G. Zong, and S. Bi, "A Family of Butterfly Flexural Joints: Q-LITF Pivots," *Journal of Mechanical Design*, vol. 134, no. 12, Nov. 2012, doi: https://doi.org/10.1115/1.4007917.