Learning Muscle Reflexes for Versatile and Dynamic Bipedal Locomotion

TECHNISCHE UNIVERSITÄT DARMSTADT

Research Topic for a Master Thesis

Motivation:

Humans achieve energetic, agile, and versatile locomotion across behaviors like walking, running, and hopping through modular spinal circuits that coordinate local neuromuscular reflexes using force, length, and velocity sensory feedback [1]. Unlike simplified mechanical spring models (e.g., SLIP), neuromuscular control inherently facilitates dynamic energy regulation, shock absorption, and multi-subfunction decoupling (stance, swing, and balance).

Existing work has achieved agile bipedal gaits mainly using model-based control or end-to-end deep reinforcement learning, which often suffer from model sensitivity or rigid, energy-inefficient behaviors. Previous studies have deployed a single virtual muscle on a hopping robot and highlighted that spinal networks and neuromuscular reflexes provide natural compliance and efficient energy regulation [2]. Integrating biomechanical neuromuscular reflex mechanisms into full-size bipedal robot locomotion control presents a promising pathway for achieving agile, adaptive, and human-like locomotion.

Thesis Goals:

The aim of this thesis is to integrate neuromuscular reflex models with reinforcement learninig framework to realize bipedal walking, transfer to robot hardware and evaluate the performance:

- Literature review on locomotion analysis and bipedal robot control.
- Extend the reflex framework from static squatting to in-place and dynamic walking. This includes simplifying the reflex gains by incorporating biomechanical domain priors.
- Train the policies in simulation environments and deploy sim-to-real on robot hardware.
- Evaluate the generated gaits in terms of stability, efficiency, and performance.

Requirements:

- Understand theory of machine learning, reinforcement learninig, basic biomechanics and robot control
- Strong python programming skills
- Hand on experience with Mujoco, Matlab Simulink Real-time, embedded system, and sim-to-real transfer are beneficial

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[1] Song S, Geyer H. A neural circuitry that emphasizes spinal feedback generates diverse behaviours of human locomotion[J]. The Journal of physiology, 2015, 593(16): 3493-3511.
[2] Zhao G, Szymanski F, Seyfarth A. Bio-inspired neuromuscular reflex based hopping controller for a segmented robotic leg[J]. Bioinspiration & biomimetics, 2020, 15(2): 026007..

CCPS Control and Cyber-Physical Systems