Feedback Controller for 3D Dynamic Walking using Reinforcement Learning and Hybrid Zero Dynamics

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❑ Bipedal Walking

- Nonlinear dynamics, hybrid nature.
- Complex, high-dimensional models.

❖ Current approaches

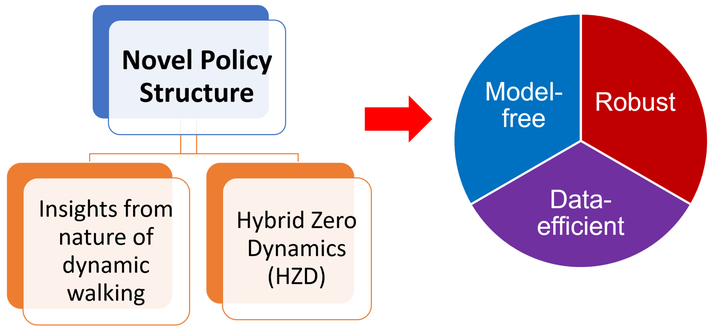
Model-based

- Computationally expensive.
- Slow for real time dynamic walking.
- Model mismatch: additional regulations.

Model-free (RL)

- End-to-end training.
- Relies on prior knowledge.
- Sampling inefficient.
- Non-smooth control signals.

❖ Objective

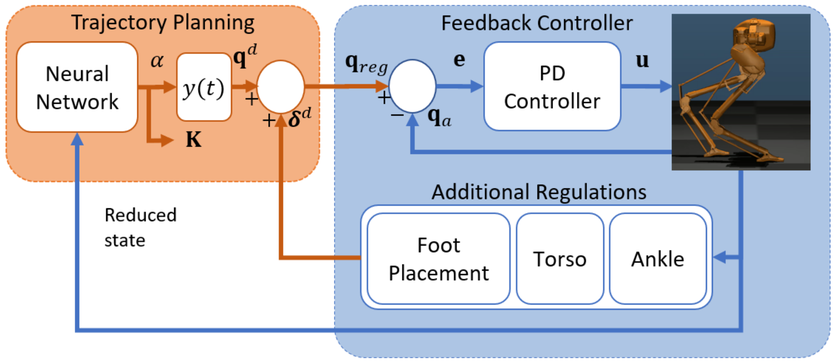


❑ Hybrid Zero Dynamics Based Feedback Controller

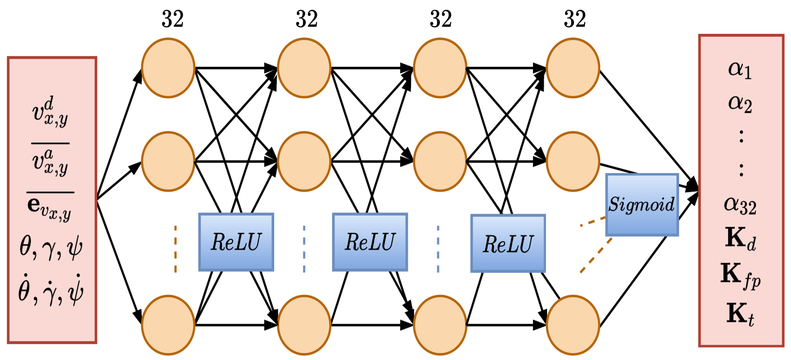
❖ Control – Learning Structure

- Finds a control policy $\pi(s_t|\theta)$ that maps a reduced order of the robot's state to (i) a the set of coefficients α that define the trajectory of the actuated joints, and (ii) a set of gains (derivative gain of PD controller, foot placement and torso regulations).

❖ Control – Learning Structure



❖ Neural Network (NN) Structure



❖ Learning procedure

- NN can be trained using any RL algorithm that handle continuous actions space (ES, PPO, DPG).

Reward function:

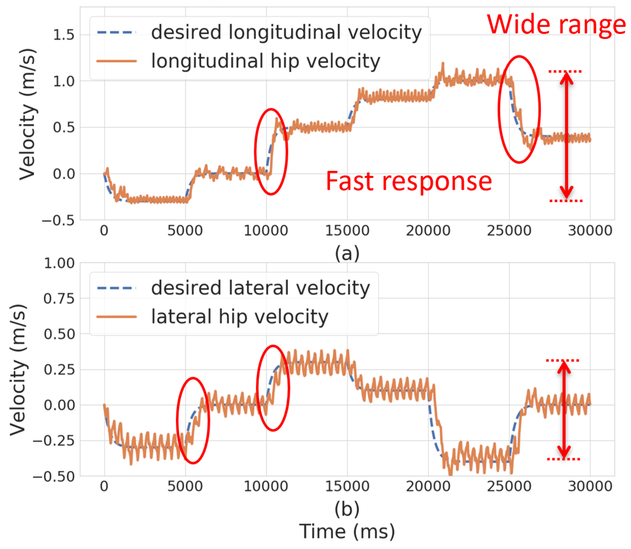
$$r = \mathbf{w}^{\mathrm{T}}\mathbf{r}$$

not falling ← → energy efficiency

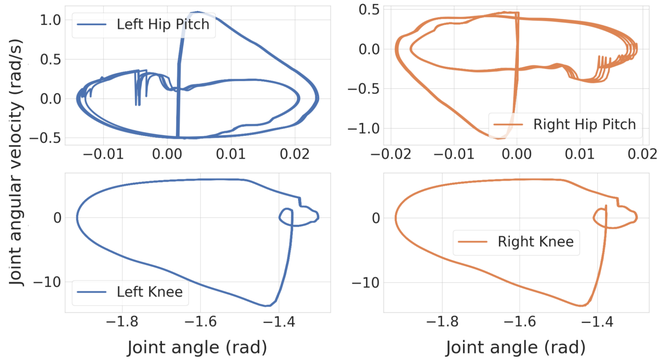
$$\mathbf{r} = \left[\underbrace{r_{v_x}, r_{v_y}}_{\text{velocity tracking}}, r_h, r_u, \underbrace{r_{COM}, r_{ang}, r_{angvel}, r_{fd}}_{\text{natural walking behavior}}\right]^{\mathrm{T}}$$

❑ Simulation Results on Cassie

❖ Speed Tracking



❖ Stability of Walking Gait



❖ Robustness