Hybrid Zero Dynamics Inspired Feedback Motion Planning for 3D Bipedal Locomotion using Reinforcement Learning

Guillermo A. Castillo and Ayonga Hereid
Dept. of Mechanical and Aerospace Engineering, Ohio State University
castillomartinez.2@osu.edu, hereid.1@osu.edu

I. Introduction

Feedback motion planning for bipedal robots is often fraught with underactuation, model complexity, and hybrid nature of legged locomotion. Existing approaches use either simple template models [1] or model-based trajectory optimization techniques [2], [3] as planning basis. Nevertheless, their applications are limited by their abilities to have a smooth, unified planner for different gaits or incorporate feedback information while walking. This work presents a lightweight reinforcement learning (RL) approach to design a feedback motion planning policy for 3D bipedal locomotion. Inspired by the Hybrid Zero Dynamics (HZD) framework, we propose a neural-network (NN) based feedback policy design using reinforcement learning. The resulting policy maps the reduced-dimensional representation of the robot to the full-dimensional stable walking motions, thereby smoothly regulate the walking speeds of the robot. The design process significantly reduces the tunable parameters in the neural network through the specific structure of virtual constraints, yields a model-free and data-efficient practice.

II. Methods

Our method incorporates useful insights from the traditional HZD control framework into the learning process of the motion planning policy. Each walking gait will be encoded as a set of virtual constraints. We then design a reinforcement learning process, in which we train a neural network policy to learn the coefficients of virtual constraints corresponds to different walking speeds. We further reduce the trainable parameters of the network by exploiting the specific structure of HZD virtual constraints. A diagram of the overall RL framework is presented in Fig. 1. The inputs of the neural network are the desired walking speed and a set of reduced dimensional states of the robot, including hip velocities and torso orientation, and the outputs of the neural network is a set of gait coefficients and control parameters. A heuristic-based feedback regulation controller is incorporated in the RL framework to provide improved robustness [4]. Independent low-level PD controllers are then used to track the desired output for each joint, which enforces the compliance of the HZD virtual constraints.

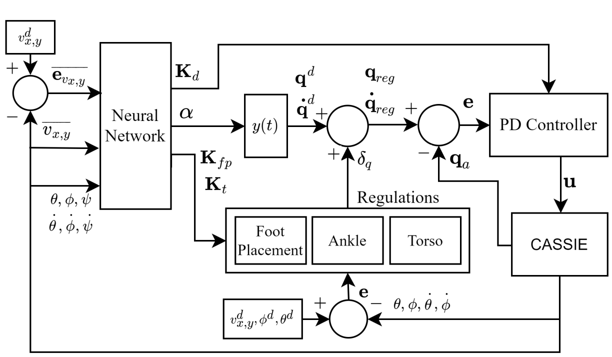

Fig. 1: Overall structure of the proposed RL framework.

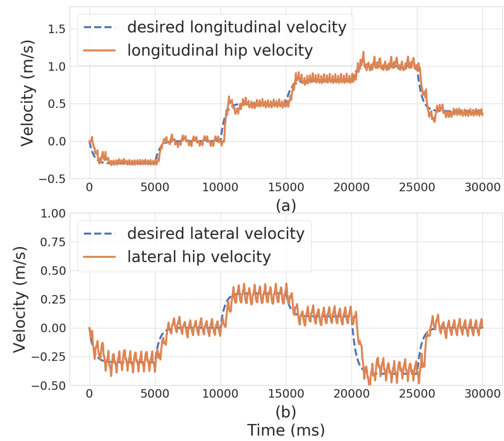

Fig. 2: Performance of the learned policy while tracking varying desired longitudinal and lateral walking speeds.

III. Results

The lightweight NN policy has only 5069 trainable parameters and can be trained less than 10 hours using a single 12-core CPU machine. With a single trained policy, the robot is capable of tracking a wide range of desired speeds in both longitudinal and lateral direction, as shown in Fig. 2. Moreover, the robot can handle up to 40 N adversarial forces without falling throughout our adversarial push tests. Visualized results of the learning process and evaluation of the policy in simulation can be seen in [5].

References

[1] S. Kajita, T. Yamaura, and A. Kobayashi. Dynamic walking control of a biped robot along a potential energy conserving orbit. *IEEE Transactions on Robotics and Automation*, 8(4):431–438, Aug 1992.

[2] M. Posa, S. Kuindersma, and R. Tedrake. Optimization and stabilization of trajectories for constrained dynamical systems. In *2016 IEEE Inter. Conf. on Robotics and Automation*, pages 1366–1373, May 2016.

[3] A. D. Ames. Human-inspired control of bipedal walking robots. *IEEE Transactions on Automatic Control*, 59(5):1115–1130, May 2014.

[4] Yukai Gong, Ross Hartley, Xingye Da, Ayonga Hereid, Omar Harib, Jiunn-Kai Huang, and Jessy Grizzle. Feedback control of a Cassie bipedal robot: walking, standing, and riding a segway. *American Control Conference (ACC)*, 2019.

[5] Simulation results for Cassie in MuJoCo. https://youtu.be/GOT6bnxqwuU. Accessed: 2019-09-15.