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MPC for quadruped locomotion

The control component to quadruped locomotion typically consists of designing the required joint torques to track a desired center of mass reference trajectory. However, some of the challenges that are faced when designing optimal controllers for quadruped locomotion are the high dimensionality, nonlinearity, underactuated, and hybrid nature of the dynamical system. Traditional methods within the legged locomotion community consisted of using Hybrid Zero Dynamics and feedback linearization to ensure stability and reference tracking capabilities. However, these control formulations are not optimal and do not generate very agile motion. Further, they are not robust to disturbances, and hence cannot typically traverse challenging terrain. Recent methods propose the use of reduced order simplified models such as single rigid body dynamics (SRBD) to model the quadruped’s floating base. This simplifies the original control design problem into hierarchical control method where the objective of the high-level controller is to find the required ground reaction forces (GRFs), which propel the floating base to track the desired reference trajectory. These GRFs generated by the legs in stance are mapped back to joint torques using a low-level stance phase controller while the swing phase controller is used to determine the joint torques of the legs in swing. For the swing phase, an inverse dynamics based controller is used while for the stance phase, the GRFs is mapped to joint torques using the constraint Jacobian.

In this project, a convex model predictive control (MPC) is proposed for the high-level optimal control design task. The objective function is to minimize the control effort (GRFs) to track a reference trajectory subject to dynamics and friction constraints and bounds on state and control inputs.

The first task is to formulate a linear state space representation of the dynamic. Since SRBD is nonlinear due to the trigonometric terms in the rotation matrices and the cross products, making the convex MPC formulation non-trivial. To deal with this, we will linearize about reference trajectories to generate a linear, discrete time state space model. Furthermore, the friction cone is nonlinear due to the 2-norm relationship. To work on this, we will use a friction pyramid constraint, which uses a 1-norm relation.

The second task is to evaluate the performance of the convex MPC in simulation by evaluating how well it can track reference trajectories under different gaits. For this, we will need to create a simulation environment which models the SRBD based off realistic robotic parameters, can handle hierarchical control scheme, generate reference trajectories, design gait parameters for executing different gaits, and visualize the locomotion task.

Potentially, we will implement this convex MPC on a robot that we build in the DIRA research lab.