Curvature-aware Model-based Planning and Control for Wheel-Leg and Track-Leg Ground Robots

Adwait Mane

ABSTRACT

Unmanned Ground Vehicles (UGVs) increasingly integrate wheels, tracks, and legs to enhance mobility in complex environments. This dissertation introduces a curvature-aware, model-based framework for motion planning and control tailored to such hybrid ground robots. The first contribution is a computationally tractable trajectory optimization formulation for wheel-leg and track-leg morphologies. A novel dynamic model approximates tracked geometry as a circulating ellipse, and the use of direct collocation with smooth analytical derivatives enables tractable optimization (<40 s) using standard solvers. The framework is validated through simulations of dynamic locomotion tasks, including step climbing and mode transitions with underactuated, multi-contact systems.

The second contribution addresses a key limitation in existing real-time control methods: the neglect of body and terrain curvature. A closed-form dynamic model is developed for rolling between arbitrary smooth planar curves, using auxiliary coordinates to define body and terrain geometry. These dynamics are suitable for Operational Space Control (OSC) with convex quadratic programming, achieving real-time performance (<3 ms) in simulation. Demonstrations include passive rolling of an arbitrarily curved body on undulating terrain, stabilization of a curved body on parabolic terrain, dynamic balancing of a 2-DoF leg, and coordinated control of a wheel-leg UGV on sinusoidal terrain.

Together, these methods enable tractable and curvature-aware planning and control for complex ground locomotion. Future work will validate the approach on a wheel-leg robot leg prototype.