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Kinematics Modeling and Push-Pull Locomotion Control for Articulated Wheel-Legged Rover for Planetary Exploration

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Abstract

Non-conventional locomotion, such as inching (Push-Pull motion), has demonstrated improved traction over conventional rolling wheels on loose terrains, making it a promising approach for planetary exploration. Achieving this motion requires high mobility rovers with wheels articulated by chains of joints, commonly referred to as legs. The push-pull concept involves keeping part of the rover stationary, typically the rear wheels, while using active joints (e.g., revolute or prismatic) to move another part, such as the front wheels, to a new position. Once the front wheels are in place, the stationary portion is relocated, and the previously moving part is fixed. This alternating sequence achieves the rover's final displacement. Precise control of such motion, especially in highly articulated rovers, requires detailed locomotion kinematics modeling and control scheme design.

A planar articulated wheel-legged rover is being developed at Concordia University's Aerospace Robotics Laboratory (CUARL). The rover features four wheels, each attached to a leg with three revolute joints, providing mobility for both the robot's base and the wheels' workspace. This work presents a generalized kinematic modeling approach that integrates the non-holonomic constraints of the wheels with the holonomic constraints of the articulated legs. A control algorithm is proposed for variable-velocity inching while tracking a predefined trajectory of the base, even without knowledge of the wheels' trajectory. This is achieved by extending local optimization to exploit redundancy and integrating a feedback control loop for push, pull, and switching phases of the inching cycle.

A high-fidelity model of the rover was developed in Simulink using the Simscape Multibody library to simulate the robot's dynamics. The model includes joint and wheel dynamics, with a wheel contact model based on the smooth spring-damper and stick-slip friction models, computing normal and friction forces. The inching control algorithm was applied in a loop with the dynamics model for testing and verification.

Simulation results demonstrate the rover's inching locomotion while tracking a trajectory, maintaining anchor wheels in a non-rotating state while the actuated wheels push forward. The trajectory closely follows the desired path, and different inching modes with variable velocity profiles were achieved.

Future work will focus on refining velocity transitions, extending the approach to curved inching, and analyzing controller stability. Experimental validation will further assess real-world performance and refine the algorithm. This work advances articulated wheeled-legged rover technology for planetary exploration.