Thesis for Doctor of Philosophy

# *Quadruped Wheel-Leg Robot System with Rope-Based Ascender Module and Trajectory Optimization*

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# ABSTRACT

## Quadruped Wheel-Leg Robot System with Rope-Based Ascender Module and Trajectory Optimization

This paper presents a wheel-leg ascending robot system for cleaning and maintenance of buildings with irregular facades, along with trajectory optimization research. To enable safe and efficient operations on complex building surfaces, we developed an innovative robotic platform that combines anchor systems for rope fixation, a rope-based ascender, and a quadrupedal wheel-leg mechanism.

The first part of this study focuses on the mechanical configuration and system specifications, analyzing design philosophy and key mechanisms to overcome limitations of conventional facade cleaning robots. Our robot employs a dual structure where the ascender module facilitates vertical movement using ropes, while the wheel-leg module navigates various obstacles and inclined surfaces.

We conducted comprehensive kinematic and dynamic analyses of both the ascender and wheel-leg components, systematically examining the constraints and characteristics of each mechanism.

Based on these analyses, we propose a trajectory optimization algorithm for optimal control of this complex robotic platform. The robot incorporates multiple degrees of freedom—2 for the ascender, 12 for the legs, and 4 for the wheels—which presents challenges in open-loop control due to excessive torque from reaction forces and torsion. This paper categorizes the robot's behavior by contact state, leg locomotion, and wheel drive across various operational scenarios.

We formulated the optimization problem by setting the robot's kinematic and dynamic equations as constraints, normalizing movement based on wheel, ascender, and directional limitations. The optimal trajectory was generated using a Quadratic Programming (QP) solver and implemented through a basic controller.

Validation in Gazebo simulation demonstrated a 12% reduction in torque and a 40% increase in Energy Stability Margin (ESM) compared to conventional postures. Physical implementation experiments showed a 30% decrease in torque standard deviation when operating on a 45-degree inclined surface.

Future research directions include improving accuracy through rope and gearbox modeling, exploring optimization with various parameters beyond torque, and extending the system to Model Predictive Control (MPC) frameworks.