Fast, Modular, and Singularity-Free Whole-Body Dynamical Equations of Multi-Legged Robots

Abstract

Modeling and control of Multi-Legged Robots (MLRs) is critical for optimizing their performance, particularly when facing significant configurational changes like mechanical damage. Traditional fixed-structure models often rely on simplifying assumptions that fail to capture full system dynamics under these conditions. In response, we propose a modular modeling approach that independently models each robot module and dynamically combines them to form a comprehensive whole-body model based on the robot's current configuration. This method simplifies the model space to a combinatorial problem of pre-modeled dynamic libraries, offering more flexibility than traditional approaches.

We employ Boltzmann-Hamel equations and screw theory to create a fast, singularity-free Lagrangian model capable of adapting autonomously to various damage scenarios without retraining or re-deriving the equations. This model, validated through a multi-legged simulation engine, incorporates contact dynamics, gait generation, and local leg control, demonstrating its effectiveness in handling off-nominal conditions. Our simulations on a six-legged robot, along with real-world sensor data validation, highlight the model's accuracy and robustness. Additionally, our method is approximately three times faster than traditional methods like the recursive Newton-Euler approach, as confirmed by comparative numerical analysis.

Bio

Sahand Farghdani is a Ph.D. student at the Autonomous Space Robotics and Mechatronics Laboratory (ASRoM-Lab) at Carleton University, where he has been conducting research since Fall 2020. He earned his BASc in Mechanical Engineering from K. N. Toosi University of Technology in 2018, developing a Model Predictive Control (MPC) for the van der Pol oscillator. In 2020, Sahand completed his MASc at the Sharif University of Technology, where he focused on control and robotics, designing an MPC for a lower limb exoskeleton aimed at rehabilitation and empowerment. His current research focuses on modeling and control of reconfigurable robotic systems, with the goal of developing an autonomous damage recovery algorithm for multi-legged robots.