



ME – PhD Thesis Defense

Compliant Feet and RL-Based Control of Quadruped

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ABSTRACT

Quadruped robots — four-legged platform inspired by animals — are designed to move across rough, uneven, and unpredictable terrains where wheeled or tracked robots struggle. Their ability to balance, adapt, and traverse complex environments makes them valuable in fields such as research, defence, logistics, inspection, and disaster response. However, achieving stable and energy-efficient locomotion in quadrupeds is challenging due to their complex leg dynamics, high impact forces during motion, and significant energy losses in motors, transmissions, and ground interactions. Improving their energy efficiency requires advances both in mechanical design—such as lightweight, compliant legs that can absorb shocks and store elastic energy—and in control strategies that optimize gait patterns, trajectories, and power usage. Despite progress, most existing quadrupeds still rely on rigid leg structures, leading to high energy costs and limited adaptability to terrain changes. There is limited understanding of how foot compliance directly affects locomotion efficiency. To address these gaps, this work focuses on integrating mechanical design improvements with learning-based control, aiming to create quadrupeds that are more energy-efficient.

We first started by formulating a simplified dynamic model of a two-link legged robot, including a passive prismatic spring at the foot. Through this model, we analyzed the fundamental effects of compliance on stance and flight dynamics. That helped us to demonstrate how spring stiffness governs energy storage and release during hopping. Building on this foundation, the study expands to incorporate a linear spring at the feet of each leg of the quadruped robots that provides compliance through a simple linear model. The two-link leg with a spring was modeled in the multibody simulation software tool MuJoCo, and simulations were performed for a wide range of values of spring stiffness to obtain the jump height as a function of the spring stiffness. Experiments performed on a two-link (thigh and shank) hardware with several springs, validated the MuJoCo simulations where an optimum spring stiffness was found to give the maximum jump height range

With these insights, the thesis transitions to the modeling, simulations, and experimentation with a quadruped with compliant feet implemented using linear springs in the legs. The quadruped was first designed using CAD models of its components, which were then imported into Isaac Gym in URDF form for simulation. Since the same CAD models were also used to build the physical robot, the simulations closely represent the actual hardware used in experiments. The mechanical structure, actuation system, and sensing framework are described in detail, along with the integration of compliant foot modules that form the core of the experimental setup. This physical system becomes the proving ground for the next phase of research: reinforcement learning-driven energy efficient locomotion. Using the rigid-body simulator NVIDIA Isaac Gym, we trained walking policies with different spring stiffness values. The results show that foot compliance significantly changes how the robot learns to walk, allowing it to achieve more energy-efficient walk.

The major challenge of this research is transferring the learned policies from simulation to reality. We deployed the trained policies on the physical quadruped robot and measured energy consumption across different stiffness values of the springs. Notably, the experimental hardware results closely align with the simulation outcomes, thereby reinforcing the conclusion that appropriately tuned passive compliance can enhance the energy efficiency of quadruped locomotion.

ABOUT THE SPEAKER

Pramod Pal is a Ph.D. student in the Department of Mechanical Engineering at the Indian Institute of Science (IISc), Bengaluru. He is conducting his research under the supervision of Prof. Shishir Kolathaya, Prof. Ashitava Ghosal, and Prof. B. Gurumoorthy in the Stoch Lab and the Robotics and Design Lab. He received his Master's degree in Mechanical Systems Design from the Indian Institute of Technology (IIT) Bhubaneswar in 2018. His research focuses on the design, modeling, and control of legged robots.

