Research Statement

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My research interests lie in legged robotics, with a particular focus on optimization-based and learning-based approaches for motion control.

During my master's studies, I worked on optimization-based control for humanoid locomotion, including convex SRB MPC, nonlinear centroidal MPC, and task-space QP-based whole-body control.

My first project, built on Cheetah Software, developed a convex SRB MPC framework for robust humanoid locomotion over multiple terrains. In this system, a QP was solved at 200 Hz to compute the ground reaction forces of the stance leg, while heuristic foot placement and cosine swing profiles were used to generate swing-leg trajectories. Combined with a linear Kalman filter-based state estimator and a simple contact detection module, the controller was deployed on the humanoid robot Wukong-IV and demonstrated stable walking on tiles, soil, asphalt, and grass, with strong robustness against external disturbances such as pushes, kicks, steel pipes, speed bumps, and curbs. A video of this work is available [here].

Building on this work, I then explored perception-aware locomotion by integrating terrain information into the control loop. To this end, I developed a nonlinear MPC planner based on OCS2 using a centroidal dynamics model that includes joint positions in the state. Compared with the single rigid body model, this formulation enables online optimization of foothold placement and swing trajectories based on terrain geometry, while also capturing the effect of limb inertia on center-of-mass dynamics, which is particularly important for humanoids due to their relatively heavier limbs. With an efficient implementation, the planner ran at 100 Hz for online replanning. Combined with a task-space QP-based whole-body controller, it enabled Wukong-IV to traverse **22° slopes** and **25 cm steps** in simulation, while increasing the maximum forward speed from **1.0 m/s** to **1.7 m/s**. A video is available [here].

Although my master's research emphasized engineering deployment more than publication, these projects gave me a strong foundation in robotics. They trained me in legged dynamics modeling, optimization-based control, and real-world controller implementation on robotic systems.

During the first year of my PhD, I have been working on data-driven modeling of deformable terrain dynamics for legged robots. In particular, I am exploring the use of Hankel matrices from behavioral systems theory to model the dynamic behavior of compliant surfaces. Related ideas have been studied in [DeePC] and [DeePC for Quadruped Locomotion]. The main idea is to use input-output data from robot–terrain interaction to construct a Hankel matrix that captures the underlying terrain dynamics, and then use this model to predict future terrain behavior and optimize robot motion accordingly. I am currently validating this approach in both simulation and real-world experiments, with the goal of publishing the results in the near future.

In parallel, I have also participated in several learning-based projects, including [ABD-Net] and [SPARK]. In ABD-Net, we introduced an inertia-propagation mechanism inspired by the Articulated Body Algorithm into policy network design, enabling more efficient and robust policy learning. In SPARK, we proposed a skeleton-parameter-aligned retargeting method for humanoid robots that outperformed GMR, together with a progressive kinodynamic trajectory optimization method that

generates dynamically consistent state trajectories and joint torque profiles. These two components provide high-quality motion references for motion editing and accelerated policy learning.

Looking ahead, I am interested in several open problems in humanoid robotics:

- **General motion tracking.** Most existing work focuses on learning a single motion, such as walking, jumping, or a short dance clip, which limits policy generalization. General motion tracking, or whole-body control over diverse motions, remains challenging for humanoid robots. Although recent systems such as GAE, TWIST2, and SONIC have shown promising results, they still fall short in tracking accuracy and robustness for highly dynamic behaviors. Recent work such as OmniXtreme further highlights both the importance and difficulty of scaling high-fidelity tracking to diverse, high-dynamic motion libraries.

- **Motion generation.** Most motion data is still collected using mocap systems, which are costly and limited in scale and diversity. Fast motion extraction from video, combined with retargeting, offers a promising way to build large-scale and diverse motion datasets for humanoid robots. With additional physics-based motion optimization, these motion references can be further improved for training general motion-tracking policies. Moreover, large language models may help map high-level natural language instructions into motion goals or references. Combined with general motion tracking for reliable whole-body execution, this could provide a promising pathway toward vision-language-action (VLA) humanoid systems.

- **Object interaction.** Most existing work focuses on humanoid motion itself, without modeling rich interaction with external objects, which is essential for real-world tasks. Existing works such as SkillMimic and HUSKY either lack hardware validation or focus on relatively limited interaction scenarios. Progress in this direction will require tighter integration of perception and higher-fidelity simulation.

- **Learning-based simulation.** High-fidelity and efficient simulators such as Isaac Gym and MuJoCo have enabled rapid progress in RL-based robotics. However, real-world effects such as deformability, friction, and dissipation remain difficult to capture with analytical models. Learning-based simulators are promising because they can be adapted using real-world data and reduce the need for hand-crafted complex dynamics. Recent works such as NeRD and RWM have taken important steps in this direction, but the field is still at an early stage.

In the long term, I hope to contribute to unlocking the full potential of humanoid robots and to grow into an independent researcher in this field.