Research Statement

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A. Introduction and Problem Statement

Robots have the potential to expand human operations into domains that are difficult to access, inherently hazardous, or physically demanding. Recent studies have introduced diverse multi-limb robotic systems for deployment across a broad range of real-world domains, expanding the settings in which robots can be used. However, designing motion remains challenging when the physical principles behind feasible and effective motion strategies are not yet well understood.

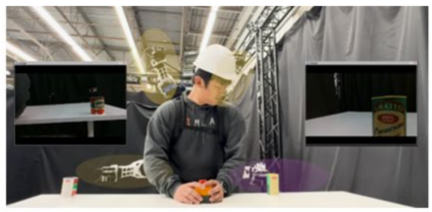
My research addresses motion generation for multi-limb robotic systems by explicitly considering physical constraints arising from robot morphology, task requirements, and environmental conditions. The goal is to establish a physics-aware design philosophy for whole-body motion generation. In each scenario, I identify the governing constraints, formulate them mathematically, and translate them into joint-level trajectories through computational architectures.

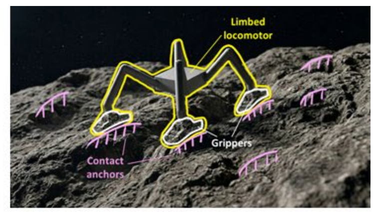
B. Background and Significance

Motion generation for multi-limb robotic systems becomes complex when it involves dynamic motion or interaction with the environment or a human user. In these scenarios, robot motion must satisfy both task objectives and physical feasibility conditions. Prior work in humanoid and animaloid robots has addressed this complexity by incorporating physical constraints into different stages of motion planning. Some approaches first plan feasible contact sequences and then generate whole-body motions that realize those contacts, while others use reduced dynamic models to guide whole-body motion before mapping it to joint-level trajectories. These studies show that motion generation strategies depend on how physical feasibility is represented in the planning process. My research extends this perspective to underexplored multi-limb robotic scenarios and contributes to a reusable design philosophy for generating feasible and effective motion under scenario-dependent physical constraints.

C. Preliminary Research (Project Pages)


Theme 1


Theme 2



Theme 3

My preliminary research has shaped this problem statement through three robotic scenarios. First, I developed a 3-DOF robotic head module for human-robot non-verbal interaction in home environments [1]. The system generated head-like gestures, performed vision-based user tracking, and adjusted its end-effector orientation to maintain consistent communication cues under different mounting conditions. This work established my foundation in real-time robotic system integration. Second, I investigated wearable supernumerary robotic limbs, which are physically coupled to the human body [2], [3]. Given this human-robot dynamic coupling, reducing asymmetric moments transmitted to the user became a motion objective while preserving manipulation performance. To address this problem, I developed a MuJoCo-based simulation environment to estimate the dynamic effects of open-chain limb motions and designed a dual-layer architecture in which the task limb performs manipulation while the idle limb generates compensatory motion. Third, I studied grasp-based locomotion for multi-limbed robotic systems in microgravity [4]. In this setting, locomotion feasibility depends on regulating motion-induced wrench within the feasible contact wrench space. I formulated the dynamic and kinematic constraints for grasp-based locomotion and developed a hierarchical locomotion planning framework that supports systematic investigation of the relationship between gait parameters and locomotion performance. Together, these studies shaped my broader goal of developing physics-aware whole-body motion generation for multi-limb robotic systems in underexplored operating domains.

D. Ongoing Works

Building on these studies, my ongoing work extends constraint-driven whole-body motion design in two directions. The first direction is adaptive gait selection for microgravity locomotion, where the goal is to connect the design intuition obtained from gait parameter analysis to an optimized motion planning process. The second direction is dynamic locomotion in gravity-dominant environments, where whole-body dynamics are treated not only as constraints to be regulated but also as resources for generating task-relevant motion. This will broaden my research from regulating whole-body wrench for stability and feasibility toward actively designing whole-body motion that actively leverages system dynamics.

E. Contributions

My research establishes a physics-aware design philosophy for whole-body motion generation in multi-limb robotic systems. Across different deployment scenarios, the key contribution is to identify the physical quantities that govern motion generation, formulate them as a motion objective or feasibility condition, and incorporate them into planning architectures that generate joint-level trajectories.

References

[1] C. Moon, S. Yamsani, and J. Kim, “Development of a 3-dof interactive modular robot with human-like head motions,” in *2023 32nd IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*, 2023, pp. 141–146. DOI: 10.1109/RO-MAN57019.2023.10309462.

[2] C. Moon and J. Kim, “Assessing the physical impact of supernumerary limbs on a human subject: A simulation study,” in *2024 46th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC),* 2024, pp. 1–4. DOI: 10.1109/EMBC53108.2024.10781831.

[3] C. Moon and J. Kim, “Strategies for moment compensation in supernumerary robotic limbs manipulation tasks,” in *2024 33rd IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*, 2024, pp. 491–496. DOI: 10.1109/RO-MAN60168.2024.10731227.

[4] C. Moon, J. Kim, and J. K. Yim, "Motion Design for Grasp-Based Dynamic Locomotion in Microgravity," Under review, 2026.