NRI: FND: COLLAB: Hierarchical, Safe, and Distributed Feedback Control of Multiagent Legged Robots for Cooperative Locomotion and Manipulation

Kaveh Akbari Hamed, Virginia Tech (Lead PI), and Aaron D. Ames, Caltech (PI)



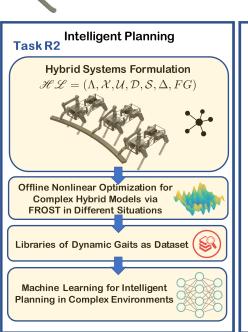
Goals and Scientific Impact

To establish a formal foundation that develops distributed and hierarchical control algorithms for safe motion control of cooperative legged robots to achieve a wide variety of tasks in complex environments



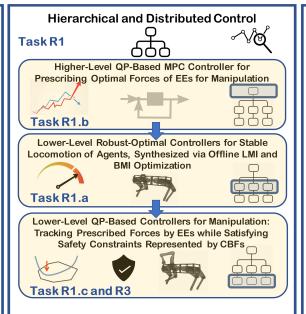
- High-dimensional and large-scale complex dynamical systems for collaborative manipulation and locomotion
- State-of-the-art techniques for distributed control of multi-agent systems are tailored to wheeled robots and UAVs, but not cooperative legged robots.





Technical Approach and Innovations

- Creation of intelligent motion planning algorithms for cooperative locomotion and manipulation
- Creation of safe, distributed, and hierarchical control algorithms for coordination of multi-agent legged robots
- Transferring the theoretical innovations into practice





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Perception data for environmental

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Vz/ Caltech

Broader Impacts on Society

- The proposed approach can address complex and agile locomotion of legged co-robot teams that dexterously manipulate objects in a safe manner in complex environments.
- Deploying legged co-robots that cooperatively work with each for a variety of tasks in different aspects of human society such as labor-intensive tasks, manufacturing, and disaster response.

Intelligent Motion Planning features (obstacles and mapping), Task R2 desired locomotion pattern, and Start Position of the Object in Complex Environments Desired trajectories for the object and agents High-Level MPC-based Convex QP **Low-Level Distributed Controllers** QP-based MPC prescribes the optimal wrenches of EEs for manipulation and steering. Task R1.a Agent 1 $\mathcal{H}_2/\mathcal{H}_{\infty}$ -Optimal Distributed Controllers Robust distributed controllers stabilize **Local Robust and** Local Robust and Local Robust and desired trajectories of the complex **Nonlinear Control Nonlinear Control Nonlinear Control** locomotion pattern, generated by the intelligent planner, for each agent. $\Gamma(x_1,\Theta,\xi_1)$ Distributed Convex QPs Local Convex QPs for Local Convex QPs for Local Convex QPs for Distributed convex QPs refine robust-Safety-Critical Control Safety-Critical Control Safety-Critical Control optimal local controllers to generate the prescribed wrenches at the EEs while satisfying safety-critical conditions, based on CBFs and CLFs. for obstacle avoidance and feasibility

Education and Outreach

 Designing a new course on dynamic legged locomotion, Partnership with VT and Caltech diversity programs (CEED and CCD), and Engagement of undergraduate students in research.



