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

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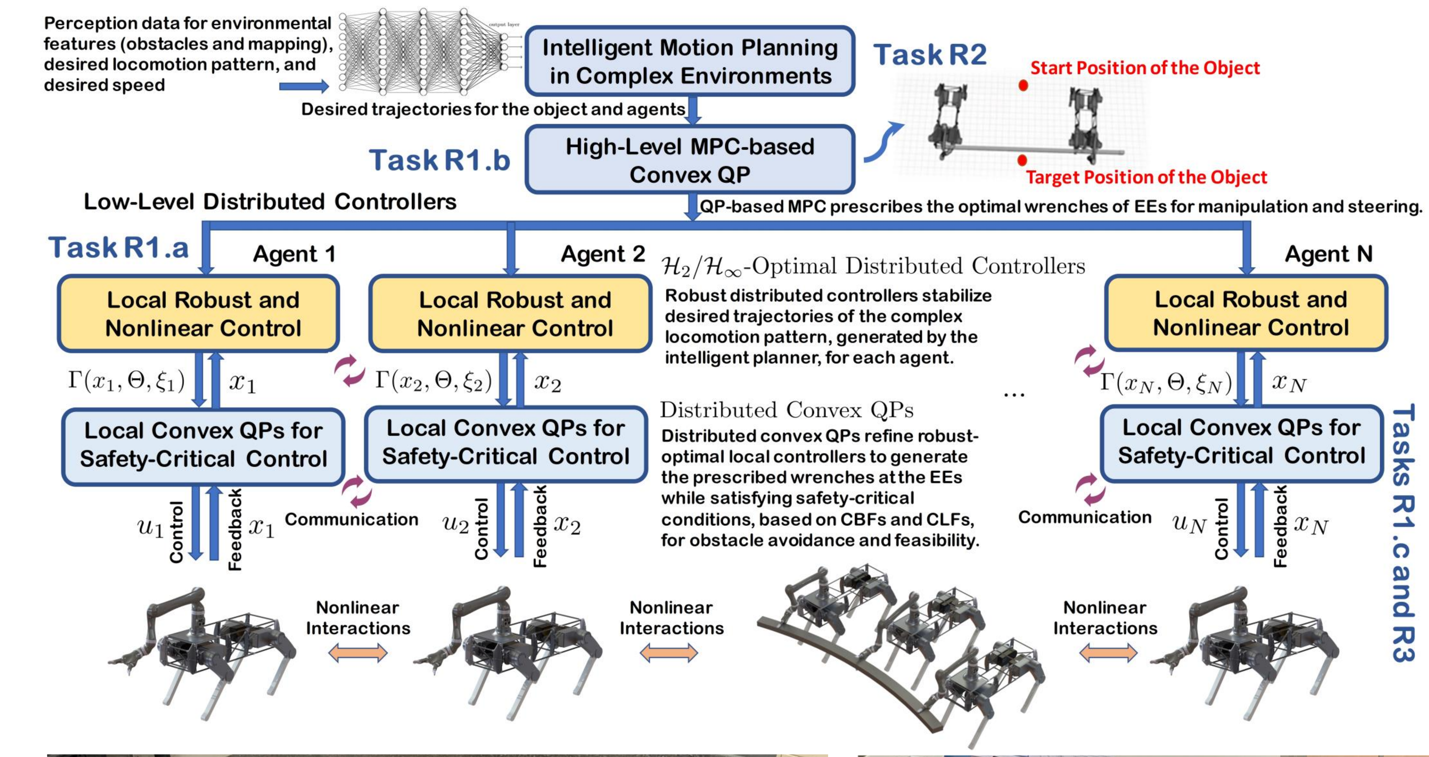
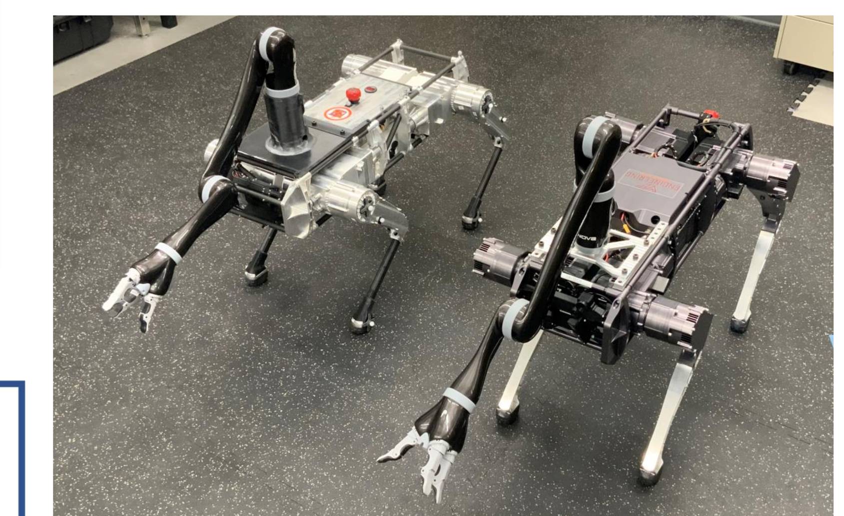
Significance and Challenges

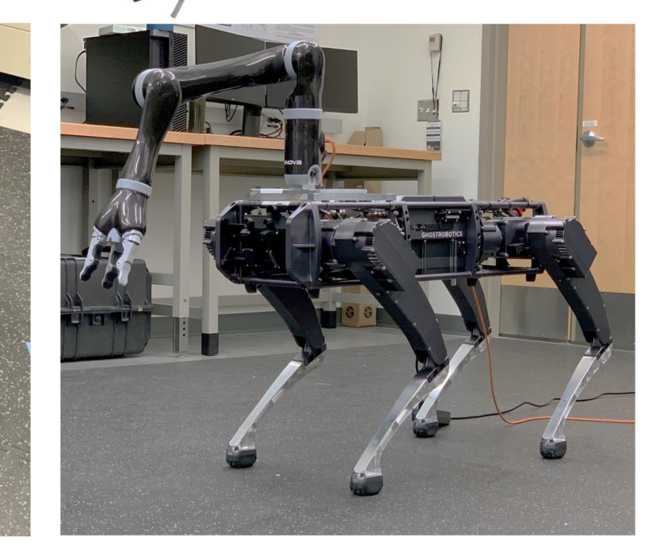
- One of the most challenging problems in deploying the next generation of **ubiquitous co-robots** is mobility in complex environments.
- Legged robots that are augmented with manipulators can form co-robot teams that assist humans in different aspects of their life such as labor-intensive tasks, construction, manufacturing, assembly, and disaster response.
- State-of-the-art approaches address the control of multiagent systems composed of collaborative robotic arms, multi-fingered robot hands, aerial vehicles, and ground vehicles, but *not* cooperative legged agents.
- The evolution of legged co-robot teams that cooperatively manipulate objects can be represented by *high-dimensional* and *complex* hybrid dynamical systems which complicate the design of distributed control algorithms for coordination and motion control.

Goals and Scientific Impact

- The **overarching goal** of this project is to establish a formal foundation, based on hybrid systems theory, scalable optimization, and robust and safety-critical control, to develop distributed and hierarchical feedback control algorithms for safe motion control of cooperative legged robots with manipulators to achieve a wide variety of tasks in complex environments.
- We aim to establish a **paradigm shift** from ad hoc control algorithms of existing legged robots that only address locomotion to resilient and versatile algorithms that address cooperative locomotion and manipulation of large-scale hybrid models of legged co-robot teams in a safe, stable, and reliable manner (**Scalability**). These algorithms will further enable legged co-robot teams to adapt to new tasks and environments with minimal modification to software (**Customizability**)

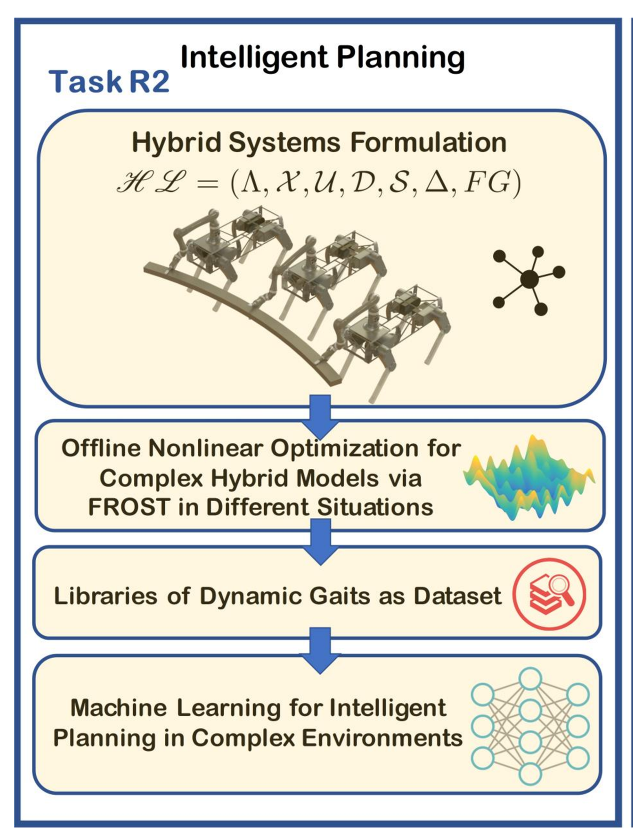


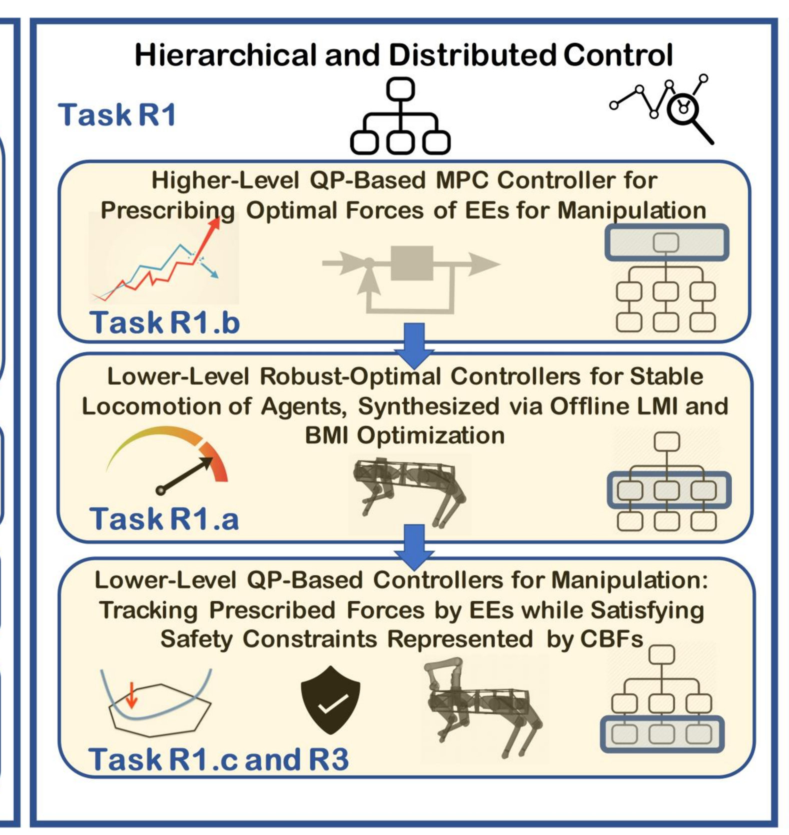




Technical Approach and Key Innovations

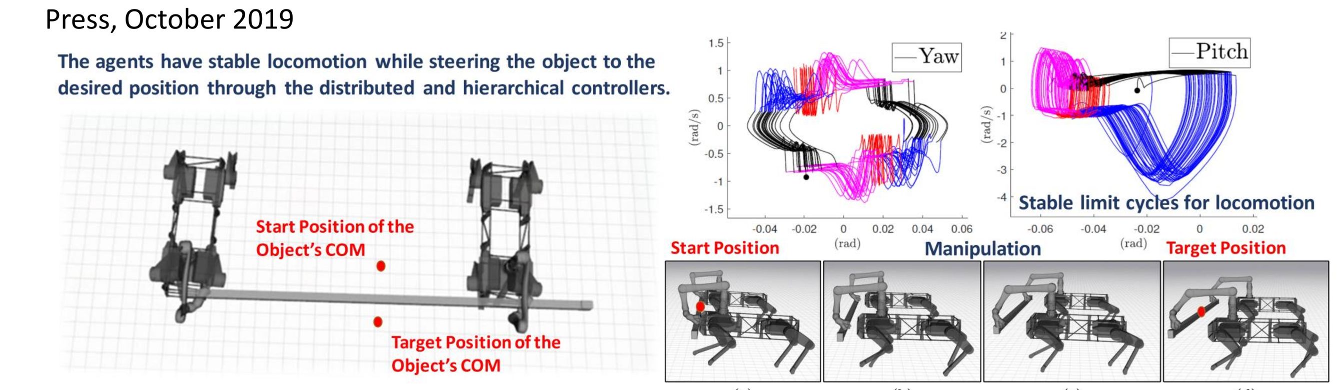
- Creation of intelligent motion planning algorithms of hybrid models of legged co-robots in complex
- Creation of distributed and hierarchical control algorithms for coordination of multiagent legged robotic systems to have robust and highly-agile locomotion patterns in complex environments while manipulating objects in a dexterous manner;
- Creation of safety-critical control algorithms, based on set invariance and convex optimization, for obstacle avoidance and having feasible contact wrenches; and
- Transferring the theoretical innovations into practice through experiments with a co-robot team consisting of two advanced and high degree of freedom quadruped robots (Vision 60) and a humanoid robot

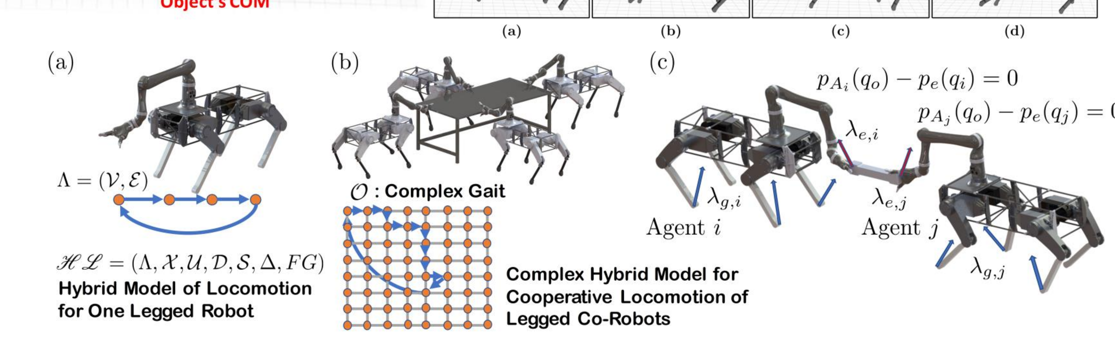




Publications

- K. Akbari Hamed, V. R. Kamidi, A. Pandala, W. Ma, and A. D. Ames, "Distributed feedback controllers for stable cooperative locomotion of quadrupedal robots: A virtual constraint approach," *American Control Conference (ACC)*, Accepted to Appear, January 2020
- K. Akbari Hamed, V. R. Kamidi, W-L. Ma, A. Leonessa, and A. D. Ames, "Hierarchical and safe motion control for cooperative locomotion of robotic guide dogs and humans: A hybrid systems approach," *IEEE Robotics and Automation Letters*, pp. 56-63, September 2019
- K. Akbari Hamed and A. D. Ames, "Nonholonomic hybrid zero dynamics for the stabilization of periodic orbits: Application to underactuated robotics walking," *IEEE Transactions on Control Systems Technology*, In Press, October 2019





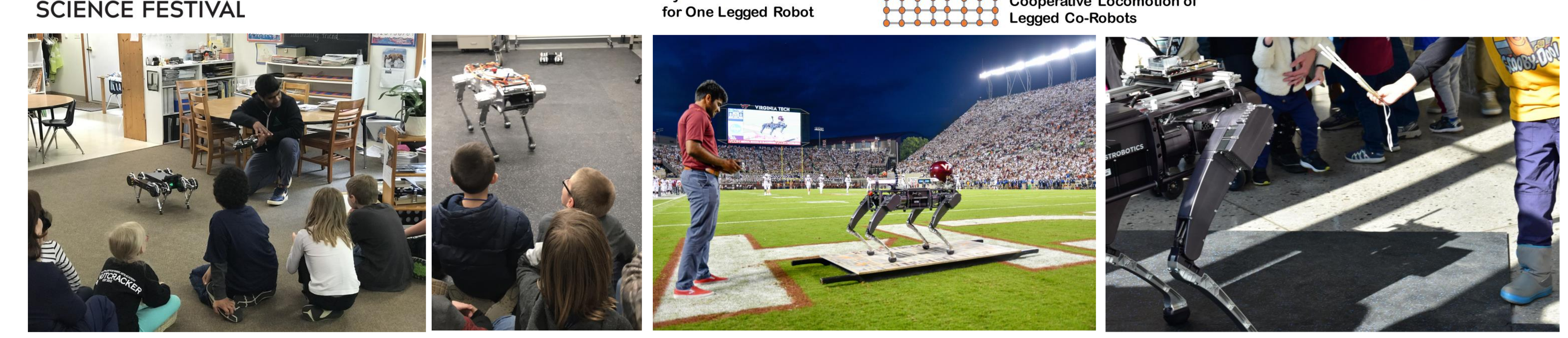
Broader Impacts on Society

- The project has *broad societal impacts*. Unlike state-of-the-art techniques that only address planning and control of one legged agent, 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.
- This control technology will therefore overcome the *key roadblocks* to deploying legged co-robots that cooperatively work with each other or people for a variety of tasks in different aspects of human society such as labor-intensive tasks, construction, manufacturing, assembly, and disaster response.

Broader Impacts on Education and Outreach

- The integrated educational plan will have a *broad impact* on advancing robotics and control education by 1) designing a new course on dynamic legged locomotion, 2) partnership with VT and Caltech diversity programs (CEED and CCD), and 3) engagement of undergraduate students in research.
- Frequent lab tours to K-12 students and teachers to inspire students to pursue an education in STEM subjects.
- Legged co-robots appeal to "kids" of all ages and our multi-disciplinary research in controls, optimization algorithms, and robotics together with outreach activities will promote STEM subjects.

VIRGINIA TECH SCIENCE FESTIVAL



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