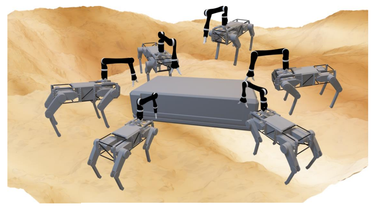
NRI: FND: COLLAB: Hierarchical, Safe, and Distributed Feedback Control of Multiagent Legged Robots for Cooperative Locomotion and Manipulation

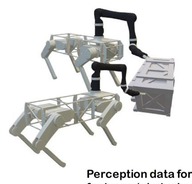
Kaveh Akbari Hamed, Virginia Tech PI, and Aaron D. Ames, Caltech PI

https://www.nsf.gov/awardsearch/showAward?AWD_ID=1924617&HistoricalAwards=false

Significance and Challenges

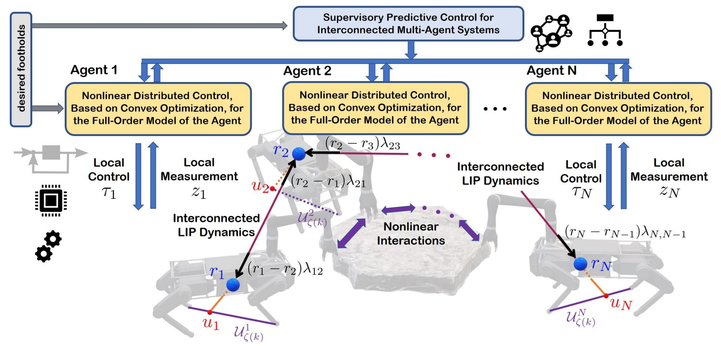
- One of the most challenging problems in deploying the next generation of **ubiquitous co-robots** is mobility in complex environments.
- Legged robots that are augmented with manipulators can form co-robot teams that assist humans in different aspects of their life such as labor-intensive tasks, construction, 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.

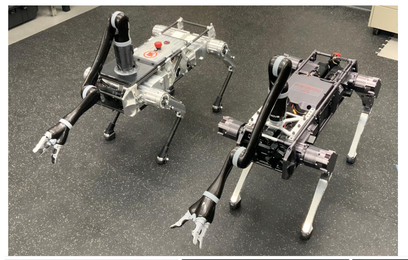


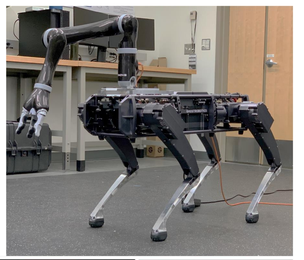


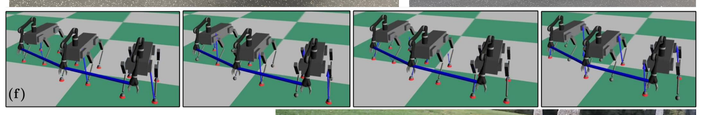
Goals and Scientific Impact

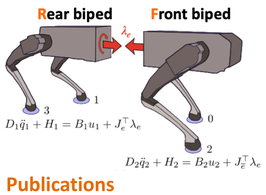
- The **overarching goal** of this project is to establish a *formal foundation*, based on hybrid systems theory, scalable optimization, and robust and safety-critical control, to develop distributed and hierarchical feedback control algorithms for safe motion control of cooperative legged robots with 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**)

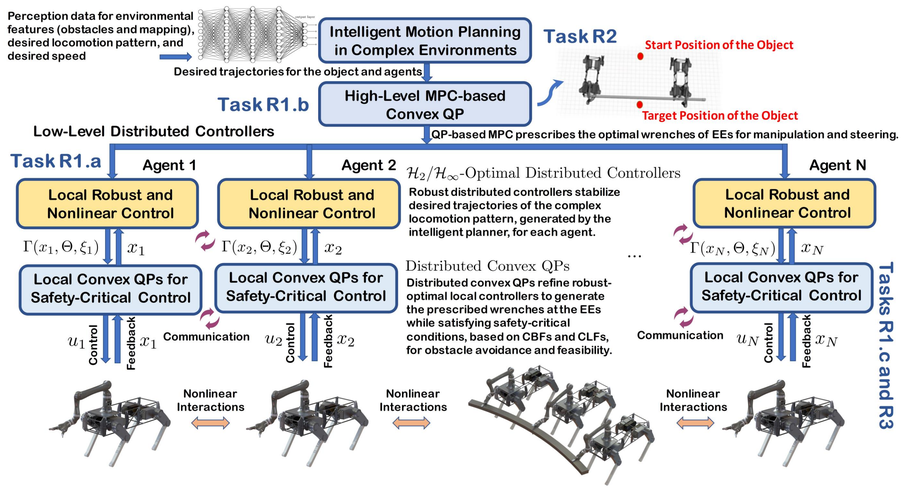












Technical Approach and Key Innovations

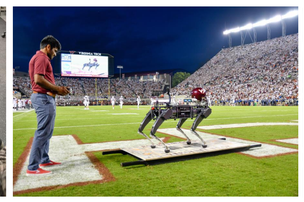
- Creation of intelligent motion planning algorithms for hybrid models of legged co-robots in complex environments;
- Creation of distributed and hierarchical control algorithms for coordination of multiagent legged robotic systems to have robust and highly-agile locomotion patterns in complex environments 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 60s)

Broader Impacts on Society

- The project has *broad societal impacts*. Unlike state-of-the-art techniques that only address planning and control of single legged agents, 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 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 controls education by 1) designing a new course on dynamic legged locomotion, 2) partnership with VT and Caltech diversity programs, 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.



Publications

- J. Kim and K. Akbari Hamed, "Cooperative locomotion via supervisory predictive control and distributed nonlinear controllers," *IEEE Robotics and Automation Letters*, Under Review, January 2021
- W. Ma, N. Csomay-Shanklin, S. Kolathaya, K. Akbari Hamed, and A. D. Ames, "Coupled control Lyapunov functions for interconnected systems, with application to quadrupedal locomotion," *IEEE Robotics and Automation Letters*, Accepted to Appear, February 2021
- K. Akbari Hamed, J. Kim, and A. Pandala, "Quadrupedal locomotion via event-based predictive control and QP-based virtual constraints," *IEEE Robotics and Automation Letters*, vol. 5, no. 3, pp. 4463-4470, July 2020
- 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)*, Denver, CO, pp. 5314-5321, July 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

2021 NRI & FRR Principal Investigators' Meeting
March 10-12, 2021

Award ID#: ECCS 1924617/1924526