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Decentralized Resilient Control Algorithms for Robust Stabilization of Hybrid Dynamical Systems: Application to Robotic Walking

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The past few years have seen an accelerated effort to design rehabilitation and emergency response robots and to develop robots with human and animal traits. Legged locomotion is extremely important in this advancement. The study of legged locomotion has been motivated by the desire to allow people with disabilities to walk (i.e., co-walkers) and to assist or replace humans in hazardous environments (i.e., co-workers). Legged co-robots that can perform at this level do not yet exist, and part of what is holding back their development and deployment is adequate feedback control theory for cyber-physical systems. While rapidly advancing technologies enable the design of increasingly sophisticated legged robots, the nonlinear feedback control laws currently used to achieve stable dynamic walking cannot scale with the increasing dimensionality of these robots. The centralized nature of state-of-the-art control algorithms prevents their transfer into local controllers for wearable robots like prostheses and orthoses. In this talk, we present a systematic design framework for decentralized feedback controllers that coordinate low-dimensional interconnected subsystems to achieve robust locomotion, overcoming the curse of dimensionality in autonomous legged robots and enabling cooperative human-machine walking with powered prosthetic legs. Our approach provides a systematic and computationally attractive solution to tuning the parameters for a general form of centralized and decentralized controllers so as to achieve exponential stability as well as and robustness. We investigate nonlinear stability tools for cyber-physical systems to formulate the problem of designing resilient nonlinear controllers as an iterative optimization problem involving bilinear and linear matrix inequalities. The power of the algorithm is finally demonstrated in designing robust stabilizing centralized controllers for walking of ATRIAS, a highly underactuated autonomous bipedal robot. It is also illustrated in designing a set of robust stabilizing decentralized controllers for walking of an underactuated bipedal robot with a decentralization scheme motivated by amputee locomotion with a transpelvic prosthetic leg.

Kaveh Akbari Hamed
San Diego State University

Dr. Kaveh Akbari Hamed is currently an assistant professor in the Mechanical Engineering Department at San Diego State University. He received his Ph.D. in Electrical Engineering with specialization in Robotics and Controls from Sharif University of Technology in June 2011. Subsequently, he held a postdoctoral research fellow position under the supervision of Prof. Jessy W. Grizzle at the University of Michigan from January 2012 to August 2014. As an assistant professor, he has been actively working on a number of different problems and approaches related to robotics, control theory, cyber-physical systems, and optimization. His research is interdisciplinary and well positioned to transform state-of-the-art methods for the control of a class of cyber-physical systems. These systems include, but are not limited to, (1) autonomous robots, (2) wearable and rehabilitation robots, (3) multiagent systems with decentralized control policies, and (4) complex systems. Dr. Akbari Hamed has recently been awarded an NSF National Robotics Initiative grant of $612,213.00 as a PI for his project to develop innovative decentralized feedback control algorithms for cooperative robotic walking with application to powered prosthetic legs. He has published his research results in the most prestigious journals and conferences of the robotics, controls and applied mathematics community including IEEE, IJRR, ASME, IFAC, and IET as well as a book published by the Wiley-IEEE Press.