Session Overview
Robot Design and Control

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Control theory to date has achieved tremendous success in the analysis and synthesis of single control systems, as well as in the development of control laws for simple groups of systems which are connected together by point-to-point wires (assumed reliable) so that information is received and processed synchronously at each subsystem. Many of these advances have been fueled by challenges in robotics: force feedback in haptic devices led to new formulations of stable control laws, coordination algorithms for robot swarms has likewise led to a theory of control for networked systems.

New vistas and challenges in robotics are continuing to push the envelope in control design. In an earlier session, new advances in the area of human-robot interaction were described. Here, the implications of this for control are discussed: the requirement for robots to interact in safe and meaningful ways with the handicapped, with soldiers, and in elder care, require new ways of thinking about a control theory that interacts seamlessly with humans, that is "self-aware", that can provide guarantees about the limits of its operation for safety. This also leads us to think about how to endow robots with "human" qualities. And, more and more, robotics are being asked to function in extreme environments: at the micro-scale level where the sheer size demands engineering innovations, to the battlefield where robustness, ease of transport, and ease of use, are paramount. This session features four exciting new research directions spanning the aspects discussed above.

One is Enough! by Lauwers, Kantor and Hollis describes *Ballbot*, a cylindrical robot the height of an adult human, designed to be agile and responsive in its interaction with people in their environments. Multi-wheel, statically stable robots of this height would be clumsy and slow, with low centers of gravity, wide bases of support, and low accelerations. Maneuvering in tight spaces, even planning a trajectory through a partially closed door, is challenging for such robots. Ballbot is a statically unstable, but dynamically stable, agile cylindrical robot whose body is supported by a single, omni-directional spherical wheel. In this paper, the challenge of designing the control law which dynamically stabilizes this system is presented, and results shown.

A Steerable, Untethered, $250 \times 60\ \mu m$ **MEMS Mobile Micro-Robot** by Donald, Levey, McGray, Paprotny, and Rus describes the smallest micro-robot ever – 1-2 orders of magnitude smaller in size than previous designs. The robot system is a cantilevered arm mounted on untethered component actuators moving on a uniform electrical grid. Here, the challenge is to design a control scheme which is simple enough to be robust at this scale. The paper discusses how the actuators are used to define two control modes, forward motion and turning, which may be coupled together to produce a control logic capable of controlling the device globally with impressively small error.

Some Issues in Humanoid Robot Design by Takanishi, Ogura, and Itoh addresses a range of new ideas and the resulting design issues for robots that interact with humans. These include the study of human motion and the human muscular-skeletal system to inspire new design structures and control laws for robot walking; new thoughts about controlling very high DOF systems; the mechanisms for realistic joint motion; and finally, the expression of emotion through arms, hands, and face (eyes, eyelids, eyebrows, lips and jaws). Exciting results on their two humanoid robots, WABIAN-2 and WE-4RII, are presented.

Finally, **That which does not stabilize, will only make us stronger**, by Kazerooni and Steger describes the design and control of BLEEX, the Berkeley Lower Extremity Exoskeleton. BLEEX is a human exoskeleton which fits around the torso, legs, and shoes of a human body (the pilot) to effectively carry 75 lb of payload while allowing the pilot to walk up to 2.9 mph – such a system has huge implications for soldiers who are continually asked to carry such heavy loads over long distances. The paper focuses on the novel control design: how does one design a control scheme which does not require direct measurements from the pilot, yet moves in such a way to shadow, with very little delay, the pilots movements so that the pilot feels very little force from the payload. This motivates a design which is counter to today's control design techniques of minimizing system sensitivity to errors or disturbances: Kazerooni has designed a control scheme which does just the opposite, and he demonstrates its success in this paper.