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Self-Stability Mechanisms for Sensor-Cheap Legged Locomotion

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Abstract
It is now well established that running animals' mass centers exhibit the characteristics of a Spring Loaded Inverted Pendulum (SLIP) in the sagittal plane (Blickhan and Full, 1993). What control policy accomplishes this collapse of dimension by which animals solve the "degrees of freedom problem" (Bernstein, 1967)? How valuable might this policy be to gait control in legged robots?

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SELF-STABILITY MECHANISMS FOR SENSOR-CHEAP LEGGED LOCOMOTION

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INTRODUCTION

It is now well established that running animals' mass centers exhibit the characteristics of a Spring Loaded Inverted Pendulum (SLIP) in the sagittal plane (Blickhan and Full, 1993). What control policy accomplishes this collapse of dimension by which animals solve the "degrees of freedom problem" (Bernstein, 1967)? How valuable might this policy be to gait control in legged robots?

A general framework for "anchoring" virtual spring loaded inverted pendulum (SLIP) mechanics in the far more elaborate morphologies of real animals' bodies (Full and Koditschek, 1999) has been motivated by successful implementation in laboratory robots (Buehler et al., 1990; Nakanishi et al., 2000; Rizzi and Koditschek, 1996). However these implementations appear to demand sensing, actuation, and computation that may be unrealistic relative to the resources that animals and practical robots might be expected to have on hand.

Can we account for stable running animal gaits without recourse to such "expensive" control techniques? If so, can we introduce such "cheap" controllers to robotics and hope to obtain similarly high performance legged locomotion?

METHODS

A new hexapedal robot, endowed with passive compliant legs and sprawled posture in essential conformance with the functional properties of exemplary cockroach runners (Full et al., 1998), exhibits mobility over general terrain exceeding that of any previous (scientifically documented) power autonomous legged machine (Saranli et al., 2001). When this machine's mechanical and control parameters are properly tuned, its mass center also exhibits pronounced SLIP characteristics (Altendorfer et al., 2001). Notably, this stable dynamical regime is achieved by a feedforward controller that drives the machine's few (only six) actuators without the benefit of any proprioceptive data (beyond the motor shaft angle measurements used to enforce the desired open loop hip position profile).

RESULTS AND DISCUSSION

At present, we do not understand enough about this robot's mathematical models to select desired gaits by first principles analysis. Stable steady state SLIP behavior is adjusted at present by systematic but almost purely empirical parameter tuning methods.

Mathematical analysis (Schmitt and Holmes, 2000) of the (simplified) horizontal plane mechanics of a running cockroach (Kubow and Full, 1999) has revealed that self-stabilization can occur in two and three degree of freedom lossless mechanisms. These models are mechanically very similar to a horizontal plane version of SLIP, motivating a search for self-stabilized gaits in the sagittal plane. Analogous study of the sagittal plane SLIP model now reveals that it too indeed includes parameter regimes that yield self-stabilizing gaits. Algebraic approximations of this parameter regime suggest the possibility of computation- and sensor-cheap feedforward control by means of parameter set points appropriate to a desired control target.

SUMMARY

The wider range of maneuvers and larger stability margins active controls can afford may well justify a greater investment in sensory technology and internal models and computation on the part of robot designers. Similarly, there is growing evidence in the animal motor literature that biological solutions to these same problems span a design space that includes both active and passive stabilizing strategies (Klavins et al., 2001). A better understanding of the tradeoffs – of just how "cheap" a machine might suffice to accomplish just what level of locomotion performance – seems essential to better robot design as well as deeper insight into animal evolution. The talk will review our growing interest and slowly increasing understanding respecting the role of self-stability mechanisms in sensor-cheap "passive" locomotion behavior.

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