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The dynamics of legged locomotion: Models, analyses, and challenges. (English)

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Authors' abstract: Cheetahs and beetles run, dolphins and salmons swim, and bees and birds fly with grace and economy surpassing our technology. Evolution has shaped the breathtaking abilities of animals, leaving us the challenge of reconstructing their targets of control and mechanisms of dexterity. In this review, we explore a corner of this fascinating world. We describe mathematical models for legged animal locomotion, focusing on rapidly running insects and highlighting past achievements and challenges that remain. Newtonian body-limb dynamics are most naturally formulated as piecewise-holonomic rigid body mechanical systems, whose constraints change as legs touch down or lift off. Central pattern generators and proprioceptive sensing require models of spiking neurons and simplified phase oscillator descriptions of ensembles of them. A full neuromechanical model of a running animal requires integration of these elements, along with proprioceptive feedback and models of goal-oriented sensing, planning, and learning. We outline relevant background material from biomechanics and neurobiology, explain key properties of the hybrid dynamical systems that underlie legged locomotion models, and provide numerous examples of such models, from the simplest, completely soluble "peg-leg walker" to complex neuromuscular subsystems that are yet to be assembled into models of behaving animals. This final integration in a tractable and illuminating model is an outstanding challenge.

Reviewer: R. Kodnar (Bratislava)

MSC:

34-02	Research exposition (monographs, survey articles) pertaining to ordinary differential equations
34C60	Qualitative investigation and simulation of ordinary differential equation models
34C15	Nonlinear oscillations and coupled oscillators for ordinary differential equations
34C25	Periodic solutions to ordinary differential equations
34C29	Averaging method for ordinary differential equations
34E10	Perturbations, asymptotics of solutions to ordinary differential equations
92C10	Biomechanics
92C20	Neural biology
93C85	Automated systems (robots, etc.) in control theory

Keywords:

animal locomotion; muscles; neural networks; periodic gaits; phase oscillators; piecewise holonomic systems; preflexes; reflexes; robotics; sensory systems; stability; biomechanics; templates; bursting neurons; central pattern generators; control systems; hybrid dynamical systems; insect locomotion; Lagrangians; motoneurons

Software:

XPPAUT

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