Adaptive Dynamical Systems for Movement Control

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We present a dynamical systems approach to adaptive controllers for locomotion control. The approach is based on a rigorous mathematical framework, which is founded on theories of self-organization.

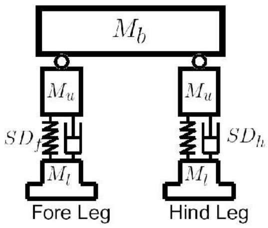
Nonlinear dynamical systems are an interesting approach for the on-line generation of trajectories for robots with many degrees of freedom (e.g. legged locomotion). However, designing a nonlinear dynamical system to satisfy a given specification and goal is not an easy task, and, hitherto no methodology exists to approach this problem in a unified way.

Nature presents us with satisfactory solutions of coordination of many degrees of freedom. One central feature observed in biological subjects is the ability of the neural systems to exploit natural dynamics of the body to achieve efficient locomotion. In order to be able to exploit the body properties adaptive mechanisms must be at work. Recent work has pointed out the importance of the mechanical system for efficient locomotion. Even more interestingly, such well suited mechanical systems do not need complicated control. Yet, in most approaches, adaptive mechanisms are either missing or they are not based on a rigorous framework, i.e. they are based on heuristics and ad-hoc approaches.

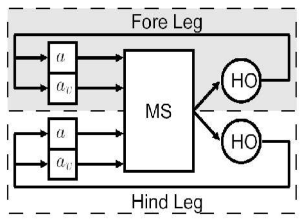
Over the last three decades there has been enormous progress in describing movement coordination with the help of Synergetic approaches. This has led to the formulation of a theoretical framework: The Theory of Dynamic Patterns. This framework is mathematically rigorous and at the same time fully operational. However, it does not provide any guidelines for synthetic approaches as needed for the engineering of robots with many degrees of freedom, nor does it directly help to explain adaptive systems.

We will show how we can extend the theoretical framework to build adaptive systems. For this purpose, we propose the use of multiscale dynamical systems. The basic idea behind multiscale dynamical systems is that a given dynamical system gets extended by additional slow dynamics of its parameters, i.e. some of the parameters become state variables. We apply the idea to a simple spring-mass hopper system (cf. Figure a). The spring mass system consists of a body with two legs attached by rotational joints. The legs contain spring-damper elements. Therefore, the hopper contains clear natural dynamics in the form of resonant frequencies.

By using two adaptive frequency oscillators we devise a simple controller which is able to initiate efficient gallop like locomotion by adapting to the resonant frequencies of the legs. Interestingly, purely local control is sufficient, i.e. the two oscillators do not have to be directly connected, for effective locomotion (cf. Figure b). The only connection is realized by the mechanical structure. Despite the simplicity of the controller and the body, the achieved locomotion is surprisingly complex and natural (cf. Figure c).



a)



b)

c)

The advantages of the framework of Multiscale Dynamical Systems for adaptive controllers are 1) fully dynamic description, 2) no separation of learning algorithm and learning substrate, 3) no separation of learning trials or time windows, 4) mathematically rigorous, 5) low dimensional systems. However, in order to fully exploit the framework important questions have to be solved. Most importantly, methodologies for designing the feedback loops have to be found and important theoretical questions about stability and convergence properties of the devised systems have to be answered.

We will discuss the application of the framework to other tasks such as humanoid robotics and ad-hoc modular robots. Ad-hoc modular robots pose a particular challenge to control engineering since traditional model based approaches as well as off-line optimization strategies are not feasible. Our approach might offer an interesting approach for controllers which are model-free (i.e. without explicit model) and on-line adaptive.