Controlling Dynamic Motions of Biped Robots with Reflexes and Motor Patterns

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Introduction

Despite many efforts in the development and control of two-legged robots, nature's solution of biped walking is still unequaled. Both the mechanical side and neural control surpass what robotics research has come up with. While the properties of the biological locomotion apparatus are fairly well understood, still there seems no technical solution for an equivalent actuation system. Unfortunately the knowledge on nature's neural control concepts is far from complete.

Related Work

Recent research results seem to support the assumption that neural motor control is of a hierarchical layout. Bizzi et al. found a spatial connection of stimulation of regions in the spinal cord of frogs and the kinematic reaction of its legs [1]. They suggested the existence of motor programs or modules creating activities of whole groups of muscles. Later results on the combination of such modules for movement show that the same modules are even used for different modes of locomotion [2]. Analysis of human motor control lead to similar finding. Ivanenko et al. used statistical methods like factor analysis or PCA to show that muscle activity patterns recorded using EMG during walking can be explained by the sum of only five basic temporal components. This holds true even for different walking speeds and on supporting body weight to various degrees [3]. A spatial mapping to the spinal cord could also be shown [4]. Further results imply that the same five motor patterns can account for both walking and running with only a phase shift of one of the temporal components [5]. Still there remains the question of a semantic interpretation of these basic patterns, and if a interpretation explains how the patterns evolved. While the observed motor patterns seem to be mostly of a feed-forward nature, one must ask how sensory feedback is incorporated. The reaction of reflexes must be combined with the muscle activation of motor patterns that are themselves modulated by various stimuli. In [6] the dynamic sensorimotor interactions in the spinal cord and at supraspinal levels are discussed.

There have been various attempts to control biped robots using methods inspired by biological insights as those just mentioned. Geng et al. implement a reflexive neural network for a small planar walker [7]. They show that fast walking is possible without planing of trajectories but rather by using local reflexes and by exploiting the passive dynamics of the mechanical system. In [8] it is demonstrated that a purely reactive sensorimotor neural network can produce a walking gait in a 8 DoF simulated biped. Only a few works can be found on controlling fully articulated bipeds, let alone experiments on real hardware. Endo and his colleagues propose the use of a neural oscillator and feedback pathways similar to Kimura's work on quadrupeds [9]. They tested the approach on the QRIO robot, but used inverse kinematics of the legs to generate trajectories.

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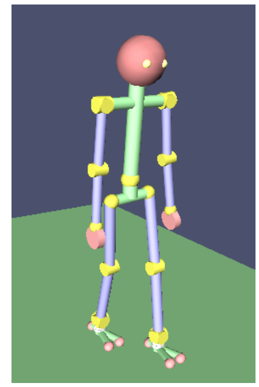
The approach described in this paper tries to incorporate features of natural locomotion control as those described above into a robotics control architecture: (1) The system is structured as a hierarchical network of control modules. This way it is possible to represent different levels of neural motor control like reflexes or motor patterns. (2) The control components are local and distributed. No elaborate models of the robot or its environment are necessary and no explicit trajectories are includes. (3) Reflexes introduce a tight sensor/actor coupling for fast responses to stimuli. But reflexes can be inhibited or react different depending of the phase or mode of locomotion as it is the case in biological control. (4) Motor patterns allow for temporal synergies of a few cooperating joints. The patterns can be modulated by descending pathways or proprioceptive inputs, i.e. by high-level modules, sensors like INS or load cells, or measurement of joint torques and angles. (5) Easy and transparent fusion of different control unit's outputs for similar actuators is possible. (6) The passive dynamics of the mechanical system and its interaction with the environment are allowed to contribute to the overall motions. The system is based on a behavior-based control framework that was successfully used before on various robots by the authors and others (e.g. [10]) and allows to implement the characteristics just mentioned.

Designing an architecture supporting the features just mentioned is not sufficient. There still remains the difficult part of finding the proper reflexes and motor patterns for the control network to do the aspired job. One of the ways proposed here is the analysis of muscle activities and temporal basic components appearing in human motor control. For parts of this data there already exists a semantic interpretation by biological research, e.g. there exists common agreement on the existence of several reflexes involved in locomotion and posture regulation. Other reflexes or motor patterns are designed to match certain muscle activities or to handle remaining control issues. One of the common design guideline for control units is to prefer torque control over position control to incorporate the passive dynamics of the robot and the environment. Instead of biological data, results from numerical optimization calculations can also give similar insights that are closely fitted to the technical system. This technique has also been used by the authors [11].



The simulated biped

In contrast to most approaches using a more biologically inspired control, the proposed method is applied to a highly complex biped robot. The fully articulated humanoid features six degrees of freedom (DoF) per leg, a three DoF spine and three DoF arms, 21 DoF in total. The robot is dynamically simulated and includes mechanical properties like elasticity as those found in the biological example. A control network for the simulated biped is developed using the proposed methodology. It enables the robot to keep balance even on heavily moving ground and against other disturbances. The network also allows for walking in a natural manner making use of the system motion dynamics.

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