A Nature-Inspired Control Technique for Adaptive Hexapedal Walking on Challenging Surfaces

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1 Motivation

An integrative view of neural circuits and mechanical components has been developed by neuroscientists and biomechanical scientists [1]. This view argues that mechanical components (e.g., muscles) cannot be isolated from neural circuits in the context of substantially perturbed locomotion [5]. The argument has been supported by cockroach experiments where more modulations of neural signals activating muscles are detected when cockroaches move over a highly complex terrain with *substantial obstacles*[1] [4].

Based on these findings, we developed a neuromechanical controller consisting of a modular neural network (MNN) and virtual agonist-antagonist muscle mechanisms (VAAMs). The MNN basically forms complex sensorimotor coordination while the VAAMs generates variable compliant leg motions of a hexapod robot. Specifically, the compliant leg motions are achieved by only changing the stiffness parameters of the VAAMs without any passive mechanisms or torque and position feedback. As a result, the controller leads to adaptive and energy-efficient walking on different surfaces.

2 State of the Art

Here we briefly discuss some aspects of neuromechanical control for legged locomotion since the motivations and benefits of neuromechanical control are in details described in [1, 5]. Many neuromechanical controllers have been developed for different types of locomotion, e.g., salamander-like trotting, lamprey-like swimming and insect-like walking. However, most of them are only presented by computer simulations owing to their complexities. For instance, a neuromechanical model of insect locomotion uses 264 ordinary differential equations (ODEs) for describing its central pattern generator, muscles actuating jointed legs, and joint torque feedback to motoneurons [2]. Besides, there are up to 26 parameters to be tuned in its muscle model, which is not practical to apply to real legged robots. In contrast, the virtual agonist-antagonist mechanism (VAAM) introduced here is a muscle model with only two tunable parameters. It can be easily applied to generate variable compliant leg motions of small legged robots. The mechanism does not require force/torque sensing at each joint or physical compliant components (e.g., springs or pneumatic artificial muscles).

3 Neuromechanical Control for Adaptive Hexapedal Walking

Generally, neuromechanical control involves interplays among neural circuits, muscles, and body mechanics in multi-legged locomotion. For example, a hexapod robot (i.e., AMOS) is controlled by a neuromechanical controller. The control can be modelled as a set of distributed and closed loops with feedforward and feedback pathways (see Figure. 1). For feedforward pathways, the controller consists of feedfoward control via descending commands (i.e., S, N_i, and O_i) from a neural circuit to muscle-like mechanisms and body mechanics. In feedback pathway, there is force sensing (i.e., F_j^{ext}) at the end effectors of the legs.

In the controller, the neural circuit is a modular neural network (MNN) (see Figure. 1 (a)), which is a biologically-inspired hierarchical neural controller. The MNN generates signals for inter- and intra-leg coordinations of the hexapod robot. The MNN consists of a central pattern generator (CPG), a phase switch module (PSM) and two velocity regulating modules (VRMs) [3]. All neurons of the MNN are modelled as discrete-time, non-spiking neurons. The virtual agonist-antagonist mechanisms (VAAMs) (see Figure. 1 (b)) are developed for simulating muscle-like behaviors (e.g., variable compliant leg motions) [8, 7]. Specifically, each joint of the hexapod robot is driven by a VAAM consisting of a pair of agonist and antagonist mechanisms. Changing the stiffness parameters (i.e., K_i) of the VAAMs enables AMOS (see Figure. 1 (c)) to achieve variable compliant leg motions, thereby leading to adaptive and energy-efficient walking on six surfaces (see Figure. 1 (d)) [6]. The video clip of the advanced walking behavior can be seen at http://www.youtube.com/watch?v=odzf8iyt5y0 .

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[1] The substantial obstacles are more than three times cockroach hip height to repeatedly perturb body dynamics.

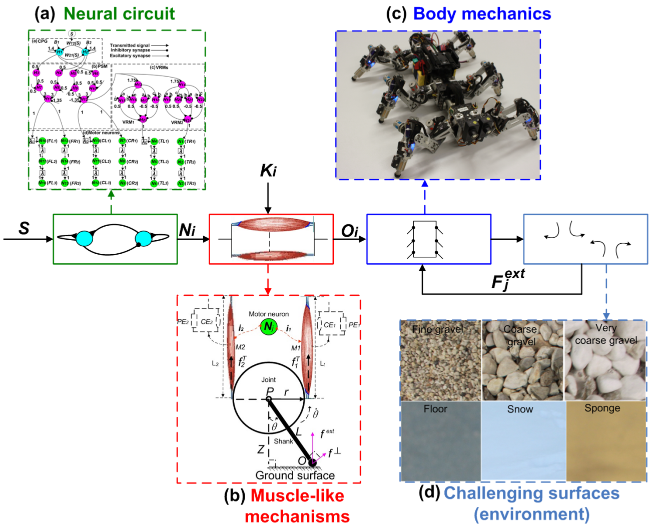

Figure 1: Neuromechanical Control. It is applied to a hexapod robot (i.e., AMOS) with 18 joints. Via neural outputs N_i ($i = 1, 2, \ldots, 17, 18$), a neural circuit activates muscles that generate position commands (i.e., O_i) to move the joints of AMOS legs. The legs then interact with the environment, which produces force feedback (i.e., F_j^{ext}) back to the system. (a) Neural circuit. It is the modular neural network (MNN) where $S \in [0.01, 0.18]$ is the modulatory input determining the speed of robot legs. The speed of its leg motion increases with increasing S. (b) Muscle-like mechanisms which are here the virtual agonist-antagonist mechanisms (VAAMs). (c) Body mechanics of AMOS. (d) Challenging surfaces (environment) which are here fine gravel, coarse gravel, very coarse gravel, slippery floor, snow, and elastic sponge.

4 Future Work and Acknowledgements

In the future, we will apply a learning mechanism for self-adjusting stiffness parameters (i.e., K_i) of the VAAMs on different surfaces. This research was supported by Emmy Noether grant MA4464/3-1 of the Deutsche Forschungsgemeinschaft (DFG) and Bernstein Center for Computational Neuroscience II Goettingen (BCCN grant 01GQ1005A, project D1).

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