Computer Simulation of the Neural Control of Locomotion in the Cat and the Salamander

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Abstract

Locomotion is an integral part of a whole range of animal behaviours. The basic rhythm for locomotion in vertebrates has been shown to arise from local networks residing in the spinal cord and these networks are known as central pattern generators (CPG). However, during the locomotion, these centres are constantly interacting with the sensory feedback signals coming from muscles, joints and peripheral skin receptors in order to adapt the stepping or swimming to varying environmental conditions. Conceptual models of vertebrate locomotion have been constructed using mathematical models of locomotor subsystems based on the neurophysiological evidence obtained primarily in the cat and the salamander, an amphibian with a sprawling posture. Such models provide opportunity for studying the key elements in the transition from aquatic to terrestrial locomotion. Several aspects of locomotor control using the cat or the salamander as an animal model have been investigated employing computer simulations and here we use the same approach to address a number of questions or hypotheses related to rhythmic locomotion in quadrupeds. Some of the involved questions are, the role of mechanical linkage during deafferented walking, finding inherent stabilities/instabilities of muscle-joint interactions during normal walking and estimating phase dependent controllability of muscle action over joints. Also we investigate limb and body coordination for different gaits, use of side-stepping in front limbs for turning and the role of sensory feedback in gait generation and transitions in salamanders.

This thesis presents the basics of the biologically realistic models of cat and salamander locomotion and summarizes computational methods in modeling quadruped locomotor subsystems such as CPG, limb muscles and sensory pathways. In the case of cat hind limb, we conclude that the mechanical linkages between the legs play a major role in producing the alternating gait. In another experiment we use the model to identify open-loop linear transfer functions between muscle activations and joint angles while ongoing locomotion. We hypothesize that the musculo-skeletal system for locomotion in animals, at least in cats, operates under critically damped condition.

The 3D model of the salamander is successfully used to mimic locomotion on level ground and in water. We compare the walking gait with the trotting gait in simulations. We also found that for turning, the use of side-stepping alone or in combination with trunk bending is more effective than the use of trunk bending alone. The same model together with a more realistic CPG composed of spiking neurons was used to investigate the role of sensory feedback in gait generation and transition. We found that the proprioceptive sensory inputs are essential in obtaining the walking gait, whereas the trotting
gait is more under central (CPG) influence compared to that of the peripheral or sensory feedback.

This thesis work sheds light on understanding the neural control mechanisms behind vertebrate locomotion. Additionally, both neuro-mechanical models can be used for further investigations in finding new control algorithms which give robust, adaptive, efficient and realistic stepping in each leg, which would be advantageous since it can be implemented on a controller of a quadruped-robotic device.

Key Words
Locomotion, Computer simulation, Central pattern generator, System identification, Gait transition, Sensory feedback, Spiking neural networks