Control principles for locomotion – looking toward biology

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1. Introduction

This lecture will focus on universal principles present in virtually all animals studied, vertebrate and invertebrate. Such universality suggests that the principles are important control strategies that are highly adaptive. Other principles are also suggested for robotic design. Examples will be given from robots of colleagues, H. Kimura and A. Lewis. The paper will provide further explanation of the principles as well as additional material including references, and lectures in PDF format.

2. CPG and muscle activation

2.1 CPG structure and basic motor pattern

Locomotion could be produced by passive mechanics as the limbs impact the environment. The muscles and tendons of the limbs have a remarkable ability to store and release energy (cf. Full), but, passive mechanics would be inadequate for swimming, uphill locomotion or for locomotion on an absorbent substrate such as sand. We also know that during locomotion a feedforward excitation to the muscles exists that can be independent of sensory feedback and brain input. The muscle activation patterns are generated by a "Central Pattern Generator (CPG)" within the spinal cord. The basic pattern, while not requiring sensory feedback (cf. however, Cruse) or brain input, does interact with feedback during movement. The CPG is a neural circuit of coupled non-linear oscillators, coordinated by strong ascending and descending fibers. The CPG structure will be elaborated and a mathematical model of the neural circuitry and coupling mechanisms presented.

2.2. Muscle co-activation

The muscle activation pattern for limbed animals is not simple alternation, but is often co-activation of antagonistic muscles. Co-activation provides stiffness and stabilization of the joints (cf. Robot by A. Lewis).

3. Sensory feedback

3.1 Resetting the step cycle

For all CPGs there is some critical feedback cue that triggers the cycle period. This mechanism adapts the cycle to the needs of the animal under all environmental situations. It will be shown how this is an important factor in a biped robot controlled by an analog VLSI CPG circuit designed by Ralph Etienne-Cummings.

3.2 Phase dependent corrections

Sensory feedback is adaptively gated through the CPG to correct for perturbations of the limb. The response to a perturbation must depend on the phase of the cycle during which it occurs. H. Kimura demonstrates this in a quadrupedal robot.

3.3 Smart sensors – muscle stretch receptors

Spindle organs, the stretch receptors of mammalian muscles, also offer potential for robotics. These receptors are highly non-linear devices, and serve to control as well as monitor the stretch of the muscle. This strategy may work for robot actuators, where the stretch receptors, in association with force receptors are used to control the activity of the actuators. Importantly, a robotic spindle has been implemented and can replicate a great deal of the function of its biological counterpart (Jaax, Hannaford, 2002).

Reference:

K.N. Jaax and B.Hannaford 2002 A Biorobotic Structural Model of the Mammalian Muscle Spindle Primary Afferent Response. Ann. Biomed. Eng. Vol. 30, pp. 84-96