Adapting Work Through Actuator Phasing in Running

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Abstract

Actuator phasing can play a significant role in the dynamics of running. Actuator phasing refers to the timing of the activation and deactivation of the actuators relative to the motion of the system. Most previous analyses of running systems have either focused on conservative models of running (with only springs in the legs and no actuators) or on models based on Raibert's hoppers, in which leg thrust is activated at one particular instant in the locomotion cycle. Using a simplified monopod model, the analysis presented in this paper reveals that there are significant advantages, in terms of efficiency and forward speed, to activating thrust at other points in the system's trajectory. The timing of actuator activation and deactivation is shown to have a direct effect on the amount of work performed by the actuators. Taking advantage of this role in regulating system energy, we first show that varying the time that thrust is activated can be used to stabilize the running monopod. We then demonstrate how monitoring actuator phasing can be used for the adaptation of stride period in an experimental hexapedal running robot. These results lead to the general idea that subtle changes in the timing of actuation can have a significant impact on dynamic movements such as running, and can be utilized for control and adaptation.

1. Introduction

The Sprawl family of hexapedal robots developed in our laboratory, shown in Figure 1, have demonstrated that a simple mechanical system with properly designed passive properties can be controlled open-loop to achieve significant speed and obstacle clearance. Recent results have demonstrated speeds of over 5 body-lengths per second on flat terrain, and the ability to overcome hip-height obstacles without significantly slowing down or altering course.

Although stable behavior is possible in the Sprawl robots for a range of open-loop parameters, the resulting performance can vary in terms of forward speed and the ability to reject disturbances. In particular, changing the stride period of the motor pattern (the time between activations of the actuators) can have a significant effect on stride length and forward velocity. It is observed that as the stride period is changed, the phasing of the actuator motor pattern relative to the motion of the system changes. Thus, we are motivated to understand the role that actuator phasing plays in running systems like our robots. This inquiry leads to the general question of when in the locomotion cycle should actuation be initiated and terminated for maximum performance. This question is applicable not only to systems controlled open-loop such as our robots, but to a general class of running systems in which energy input can take place at different points in the locomotion cycle, as either a function of sensory input or a predetermined motor pattern.

In this paper, we first describe the dynamic monopod model used to analyze the role of actuator phasing in running. Simulation results establish a relationship between work and actuator phasing. We then relate work to performance in the subsequent section by examining the continuum of steady-state trajectories of the system that arises when thrust activation is varied. The effect of varying thrust timing on the motion of the monopod is used as the basis for a proposed alternative to Raibert's "neutral-point" foot-placement controller for stabilizing a monopod. The established relationship between work and actuator phasing is also used in the slow-rate adaptation of stride period in our hexapedal robots. Finally, we present our conclusions.

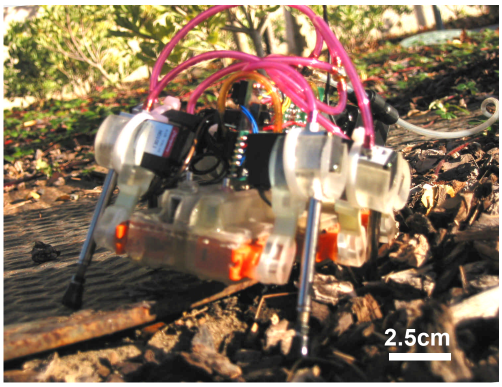

Figure 1. Although the Sprawl family of robots can achieve robust locomotion without sensory feedback, the ability to transition effectively between different types of terrain will require adaptation of the open-loop parameters.