Leg Design and Control for Fast Locomotion

Andre Seyfarth, Hartmut Geyer & Hugh M. Herr

Artificial Intelligence Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

http://www.ai.mit.edu

The Problem: Running with segmented legs. (a) Why do biological limbs operate as they do? What are the mechanical advantages? (b) How to transfer the nature's patents to technical solutions?

Motivation: A linear spring-like leg behavior is found in human and animal running [4, 2]. Although some technical systems were able to mimic running with such elastic legs within a range of different speeds and gaits [7, 8] it is still not known why biological legs employ this behavior. Until now there is no running robot with segmented legs. With regard to the reduced contact times at high speeds a smart design of the actuators and material properties and a careful selection of the leg geometry (segmentation, intersegmental angular arrangement) becomes crucial for stable running.

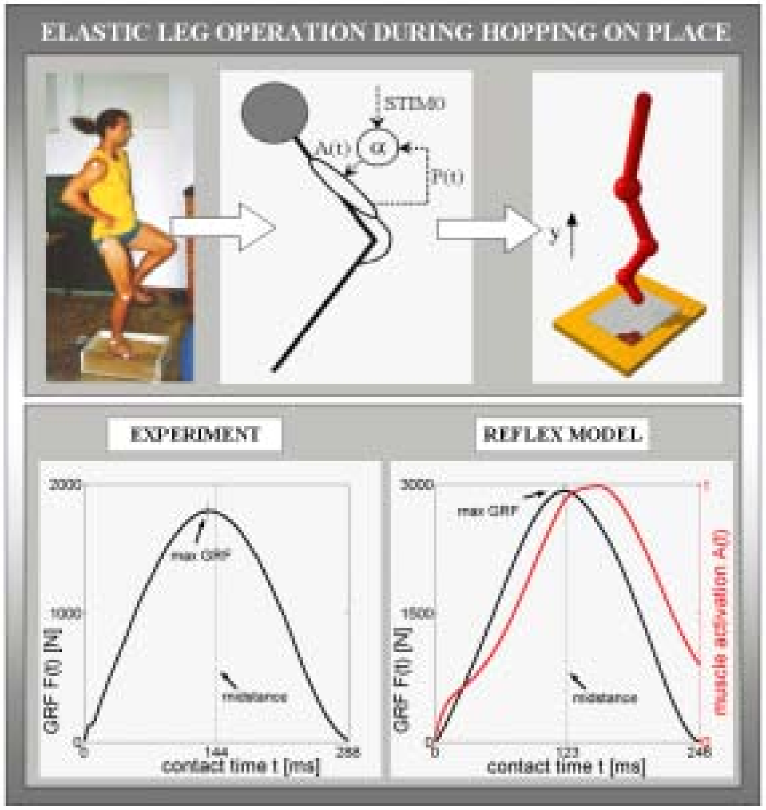

Figure 1:

Previous Work: Blickhan [9] and McMahon and Cheng [11] introduced a simple spring-mass model to approximate this generally observed force pattern. This representation of the leg by a linear spring was successfully applied by biologists [2, 10] and bioengineers [6] to describe and predict animal and human locomotion. Recently, it was found [1] that running with properly adjusted elastic legs is self-stabilizing and covers slightly changed leg adjustments (e.g. leg stiffness) and rough terrain. On the musculo-skeletal level a spring-like leg operation can be obtained if a positive (and biologically motivated) feedback of the muscle force is introduced [5]. This slightly more detailed representation of the biological limb could successfully substitute the spring-mass template for stable continuous running.

Approach: (a) Learning from biology. Elucidate the functional hierarchy in fast locomotion based on a series of simplified forward dynamic mechanical models. The movement criterion for running [1] is applied to prove the approaches. Two topological levels are addressed: the intersegmental level (internal leg model) and the multiple leg level (external model). On the internal level biologically observable muscle-reflex complexes are applied to adjacent joints in a skeletal frame. This allows studying of the intersegmental coordination and to identify possibly operating control circuits. On the external level the leg-spring template is divided into separate legs. Depending on the attachment of the legs to the supported body and the specific leg adjustment (stiffness, position) a natural sequence of contact and swing phases of each individual leg can be obtained. This allows to investigate mechanically self-maintained gaits and to estimate the importance of higher control mechanisms.

(b) Transfer to technological solutions. Our aim is to prove whether there are simple control schemes to generate different tasks (e.g. continuous hopping) using a versatile technical actuator within a segmented frame. This implies to recognize the fundamental actuator properties solving this problem. Recent studies on muscle control [5] suggest that biological actuators are well capable to fulfill several standard procedures with simple feedback pathways. Our approach is to investigate to what extend a single joint extensor based on a technically available actuator [3] can generate a spring-like operation of a two-segment leg. Motivated by the biological sensory feedback, the role of single-loop feedbacks in fast periodic contact tasks (e.g. hopping, running) is addressed. This will provide a better understanding on the necessary actuator properties for spring-like leg operation.

Impact: Traditional walking and running machines (mobile robots) require an increased control effort at higher speeds. The functional understanding and generalization of biological locomotion will lead to artificial legged systems, which are mechanically self-stabilizing at higher speeds and therefore reduce the control effort. The impact of this research can be found in robotics (e.g. fast pedal systems), prosthetics (e.g. adaptive running prosthesis), sport science (e.g. optimization of running techniques), and medicine (e.g. applying FES for hemiplegic patients in accordance to the identified natural control schemes).

Future Work: In the next year we will verify the models with experiments on human hopping and running in cooperation with the Balgrist Hospital in Zurich (Switzerland). Using an agile force plate movable in 3 axes we can introduce defined disturbances to continuous hopping. On an instrumented treadmill with optional obstacles (moving synchronized to the belt) we can investigate the variability and robustness of human running. The observations of both experiments will be compared with the model predictions.

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