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50. Internationales Wissenschaftliches Kolloquium
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André Seyfarth / Jürgen Rummel / Fumia Iida

# Biomechanics of Locomotion


## ABSTRACT

What can we learn from our legs? It seems to be very natural that we are able to walk and run in a variety of environments. However, if people try to build machines imitating human or animal locomotion these robots often move quite clumsily and sluggishly. But what do we have to do differently to build better walking and running machines? Should we use faster controllers or better sensors? Do we need stronger motors or more precise technologies?


## INTRODUCTION

It seems to be a long dream to build machines which imitate the natural movements of animals and humans. However, if one tries to copy the segmented body into a mechanical construction it usually becomes difficult to generate the smooth trajectories as observed in the biological archetype. Why is that the case?
On might argue that we do not have sufficiently powerful actuators to provide the required joint torques or that we still suffer from the limited computational capacity to process all sensory data fast enough in order to calculate the corresponding motor commands.
On the other hand, there have been a couple of passive walking machines [1, 2] demonstrating that legged locomotion could well be a rather autonomous process requiring only very little sensory feedback or control. However, these robots are imitating human walking by using a knee lock keeping the knee angle straight during the stance phase. I nature, humans prefer to flex their legs in the swing phase and the stance phase. The results in a much more compliant leg function with only small vertical oscillations of the supported body. The question we ask here whether we do need a sophisticated control to imitate such walking movements in an artificial legged system. Furthermore, could it be possible to construct legs which are equally capable of walking and running?

## METHODS

To approach these questions we built a series of very simple hopping and walking robots (Fig. 1) to learn more about appropriate feedforward control strategies for legged locomotion. These robots were built in a rather unspectacular manner using just a few components like servo motors, metal segments, revolute joints, rubber and springs. We explored the mechanical behaviour of these robots for a given oscillatory movement of the servo motor and compared that to experimental data of walking and running.

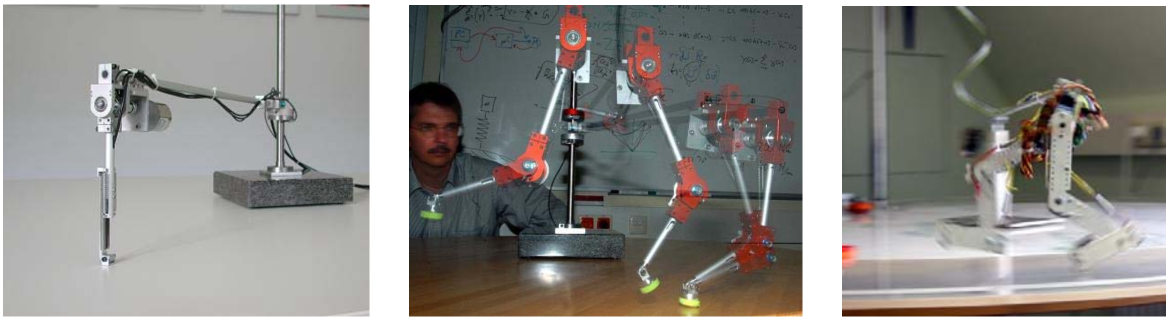

Fig. 1: Legged robots used to investigate the control of elastic legs for locomotion. To obtain stable locomotion, in all three prototypes a simple feedforward harmonic oscillation of the hip motor was sufficient.
**Left:** Pogo-stick hopper with actuated hip. **Middle:** Two-segment leg with elastic leg joint and actuated hip.
**Right:** Biped robot with two three-segmented elastic leg and actuated hips.

## RESULTS

The experimental analysis of the legged robots revealed that for a sufficient compliance of the leg a very simple hip control strategy based on a sinusoidal joint kinematics was sufficient to achieve stable locomotion.
The performance of the pogo-stick hopper was robust with respect to variations in mean leg angle (ca. 5-10% variation for >80% of maximum speed) and hip frequency (10-20 % variation for >80% of maximum speed).
For the two-segment leg forward and backward locomotion was observed for different hip frequencies. The leg joint pointed forward for higher frequencies and backward for lower frequencies.
The bipedal robot could produce stable forward walking for a large variability of hip oscillation frequencies. It is important to mention, that for both hopping and walking, the feedforward control approach of the hip was identical: a simple sinusoidal joint kinematics.

## DISCUSSION

So far, we got some insights about the role of leg segmentation and motor control on the performance and stability of locomotion. Furthermore, we learned more about the role of knee flexion during the stance phase of human walking. The comparison with experimental data on human walking and running show that similar joint kinematics can be obtained by the robots based on the dynamics of passive elastic legs.
In future, we aim to work on simple robots which are capable to walk and run mainly based on their mechanical design rather than on a highly sophisticated control system.

**References:**
[1] McGeer (1990) Int. J. Robotics Res. 9, 62.
[2] Collins et al. (2005) Science; 307: 1082-1085.

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