EMERGENCE OF GAIT IN LEGGED SYSTEMS

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What is special about our legs such that we do use them daily without any effort? And what makes legged locomotion special compared to other types of locomotion?

One of the basic observations in human and animal locomotion is the existence of gaits, e.g. distinct movement patterns with characteristic curves of the joint kinematics and the corresponding ground reaction forces. In humans we observe just two gait patterns, walking and running, whereas in many animals a repertoire of different gaits can be found.

What are the common design and control principles of legged locomotion from which one could derive the individual gait patterns? To approach this issue, (1) we performed experiments on human locomotion, (2) we modeled the dynamics of legs in computer simulations and (3) we built a series of legged robots to explore the behavior of a physical model in a real-world environment.

In **experiments on human locomotion**, we found that during the push-off phase there was an *in-phase* relationship of knee and ankle extension in running but an *out-of-phase* relationship of knee flexion vs. ankle extension in walking. Hence, the knee joint is extending during running but bending during walking. The ankle joint, at the same time, is extending in both gaits.

In a **computer simulation model**, we found that walking could be understood as a sequence of single and double supports of a *pair of compliant legs* similar to the well-known spring-mass model (such as the pogo stick leg, figure **A**).

Gait changes from walking to running could then be considered as an energetically driven transition from a region where double support phases do occur to a second region where only single-support phases and flight phases are present (Geyer et al., this conference). However, such a simple representation of a leg seems not sufficient to explain the experimentally observed change in the coordination of the leg joints between walking and running.

This leads us to the **role of leg segmentation**. In a series of robots with segmented legs (figures **B, C, D**) we investigated the influence of leg segmentation and joint stiffness on the dynamics of locomotion. Here, the leg was actuated only at the hip joint by an electric motor introducing a sinusoidal joint kinematics.

For elastic two-segmented legs (figures **B, C**) we found forward or backward hopping depending on the hip control (frequency, leg orientation). In contrast, stable walking patterns could be observed in a bipedal robot with elastic three-segmented legs (figure **D, E**). Here, the **experimentally observed out-of-phase coordination** of knee and ankle joint was reproduced by attaching several springs to the purely passive leg. The control of the hip joint was kept identical to that of the hopping robot. Hence, elastic properties in a segmented leg could be responsible for the observed gait-specific leg kinematics.

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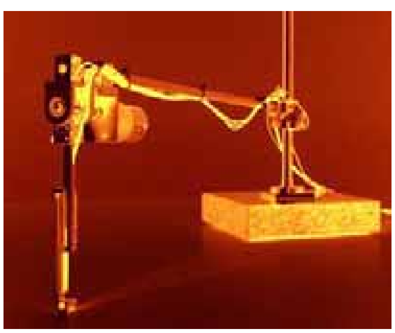
A

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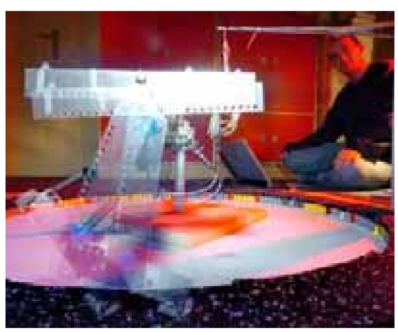
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