Walking robots are complex systems because of their nonlinear dynamics and interaction with the ground. Although traditional control methods, based on the tracking of a reference signal, can be applied, they generally require a significant amount of energy. On the other hand, research has shown that walking in itself requires little energy, and many experimental robots have been built that walk with high efficiency. General analysis and control tools for such efficient walkers, however, are lacking, and many results are based on engineering intuition and ad hoc solutions.

This thesis aims to provide a framework for modeling, analysis, and efficient control of walking robots. The framework uses a port-Hamiltonian system description to express the dynamics of rigid mechanisms and their interaction with the ground. The structure of the resulting models forms the basis for the development of general analysis and control techniques.

The proposed framework extends well-known modeling methods to a broad class of rigid mechanisms with a configuration space described by any combination of Euclidean components, Lie group/algebra components (such as ball joints), and nonholonomic components (such as non-slipping wheels). The derivation of the corresponding model equations is a systematic, modular process, and hence suitable for software implementation. Two different 3D contact models are presented: a compliant contact model, described by a spatial spring/damper and mainly suitable for simulation, and a rigid contact model, characterized by a momentum projection on impact and mainly suitable for analysis. All results are based on coordinate-free concepts and descriptions.

Using the structure of the models, the problem of finding efficient walking gaits is cast as a numerical optimization problem. This setting allows one to optimize not only the joint trajectories but also the mechanical structure of a walking robot. The approach is illustrated by computing the most efficient gaits for three different walking robots. It is shown how the walking speed of a simple planar passive (i.e. unactuated) robot on a slope can be changed by adjusting its mass distribution, and how a three-dimensional robot with a trunk walks most efficiently if the mass on the trunk is located as low as possible.

Finally, three control techniques for efficient walking are presented. The first control technique uses the computed optimal trajectories to define new coordinates that explicitly reveal the tracking performance. The resulting controller is power-continuous, tracks the trajectory asymptotically, and acts only to compensate for disturbances – not during nominal, natural walking. The second control technique stabilizes the walking behavior of a kneed experimental robot by means of a single PD controller on the hip joint. The third control technique uses foot placement to increase the robustness of a three-dimensional walking robot, and to control it to follow a reference path.