Modeling Framework and Software Tools for Walking Robots

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1 Port-based modeling of walking robots

In research on passive dynamic walking, the aim is to study and design robots that walk naturally, i.e., with little or no control effort. McGeer [1] and others (e.g. [2, 3]) have shown that, indeed, robots can walk down a shallow slope with no actuation, only powered by gravity.

In this work, we derive mathematical models of walking robots to better understand the dynamics that determine the walking behavior, and to design controllers that e.g. increase robustness against changing environments. We use the port-Hamiltonian framework, as it has the advantage of explicitly showing energy-flows inside and into the system. Thus, it allows a direct efficiency study as well as the possibility to connect external elements in a 'physical' way using ports, instead of using just torque/force signals.

2 Software for rigid mechanism modeling

As the main backbone structure of the model, we take a free-floating mechanism comprised of rigid links interconnected by ideal joints. The assumption of rigidity is reasonable for walking robots, as the operation frequency is low and the robot is often designed for high stiffness.

A software program has been developed to simplify the modeling process of rigid mechanisms. In the program, the user can create and interconnect rigid bodies in a 3D graphical user interface. The software then outputs a set of explicit dynamic equations describing the mechanism, with as minimal set of states the absolute position and orientation of a reference body, the internal coordinates linking the other bodies, and the momenta. The model also has power-ports to facilitate connection to external forces and components, such as the ones shown in Figure 1.

The software is currently being extended to more general 3D mechanical systems, e.g. to include closed kinematic chains, ball joints, and gear systems.

3 Impact-based contact modeling

In order to create possible walking motions, a model of ground contact needs to be added to the model of the free-floating mechanism of the previous section. In this work, we look at the modeling of relatively hard contact between feet and ground, such as can be expected for the contact between aluminum robot feet and our laboratory floor.

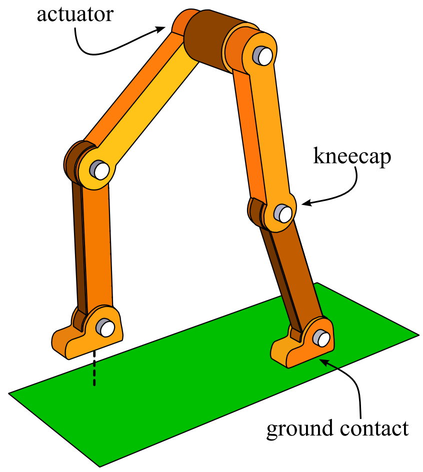

Figure 1: Example of a walking robot with several external forces acting on it.

The use of springs and dampers to model hard contact leads to stiff differential equations, which can cause problems when used in simulation. Instead, we assume that on impact, the ground applies an impulse force to stop the foot instantaneously, thus causing a jump in the momenta of the mechanism. After impact (during the contact phase), normal and tangential constraint forces are applied to keep the foot from penetrating and sliding over the ground.

References

[1] T. McGeer, "Passive Dynamic Walking," *The International Journal of Robotics Research*, vol. 9, no. 2, pp. 62–82, April 1990.

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[3] S. Collins, M. Wisse, and A. Ruina, "A Three-Dimensional Passive-Dynamic Walking Robot with Two Legs and Knees," *International Journal of Robotics Research*, vol. 20, no. 7, pp. 607–615, July 2001.