

Walking control of fully actuated robots based on the Bipedal SLIP model

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1 Introduction

Everyone has experienced that different kind of walking patterns are applied when moving on different terrains and with different goals. Beside the usual distinction between walking and running, in fact, it should also be considered that walking trying to avoid obstacles is different from walking on a flat obstacles-free surface. In the latter case everyone will walk "without thinking", to a more or less constant speed, in the most comfortable way possible. It is then quite natural to try to reproduce stable periodic walking patterns also for the robot. We are interested in an adaptable behaviour, meaning that the robot should be able to reproduce different walking motions and in particular different periodic gaits. Therefore we need to influence via the controller the dynamics of the robot.

Biped locomotion is definitely a key feature for humanoid robots. The classic approaches in this field are essentially two. In the first one the inverted pendulum simplification and the zero moment point (ZMP) are used to make the robot follow predefined footprints [7, 3]. In the second one the actuation effort is minimized trying to build passive walkers like robots which can exhibit a periodic motion [4, 1, 6]. The starting point in our approach is the spring loaded inverted pendulum (SLIP) [2, 5]. Given the initial condition and appropriate parameter values it is possible to obtain a periodic pattern (limit cycle) for the center of mass (CoM) resembling the motion and contact force profile obtained in human walking.

2 Own approach

We propose an approach to generate and stabilize a periodic walking motion for biped robots. This is achieved by mapping, via the controller, the simple dynamics of the bipedal SLIP to multi-body robots, as it is conceptually shown in Fig. 1, with the advantage to not be tailored to a specific motion but capable of a variety of patterns. In this way we do not plan any trajectory for the CoM, but rather we control the robot to follow a dynamic behavior, resulting in a stable periodic gait. An architecture with two control layers is used, as it is shown in Fig. 2. The first layer is responsible to cope with the loss of energy at the impact of the swing leg with the floor. The energy control law acts based on the state and is not only re-injecting energy in the system any time the total level is decreasing but also dissipating energy

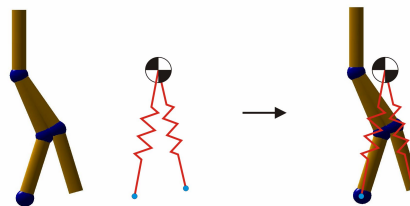


Figure 1: The idea is to reshape, via the input torques, the dynamics of the robot in order to make it behave as close as possible to the SLIP.

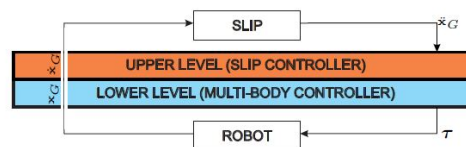


Figure 2: Conceptual architecture of the controlled system. The controller plays the role of an interface between the virtual SLIP and the real robot.

when the level is increasing. Intuitively this must lead to a stable oscillation corresponding to the desired level of energy. Then the focus is moved to the swing leg trajectory. While in the SLIP, due to the assumption of mass less legs, the swing leg can instantaneously move to its target configuration, this is obviously not true for the real robot. We define a virtual constraint which relates the configuration of the swing leg to the one of the stance leg. The virtual constraint, when fulfilled, will ensure that the target configuration of the swing leg is reached before the touch down. Finally the second layer in the control architecture will ensure that the prescribed dynamic and the virtual constraint are satisfied. Two different approaches are implemented for the lower level: in the first one, we aim at exactly reproducing the same acceleration that the controlled SLIP would have when put in the same condition, while in the second one, we aim at a simpler control law without exactly reproducing the aforementioned acceleration. The latter case is equivalent to considering a SLIP with additional external disturbances, which have to be handled by the upper level controller. Both approaches can successfully reproduce a periodic walking

pattern for the robot.

3 Discussion

It is important to relate both the desired dynamics and the virtual constraint, to the state of the robot rather than to the time. In this way it is possible to avoid, for example, that the desired behaviour requests to reproduce a force given by the two virtual springs even if the robot is in single and not double support. This would result in unnatural or even unfeasible torque requirements for the motors. While, from a computational point of view, the implementation of the proposed control laws for the lower layer is not more difficult than for the usual force control laws, it should be mentioned that also the additional constraint of the ZMP has to be taken into account when a finite support polygon is considered. Therefore, it could be useful to plan a swing leg trajectory that helps to satisfy this constraint. Since we reproduce the behaviour of a SLIP model, also the stability analysis will be based on the same approach. In other words we will consider a Poincaré map for the system. To be precise it should be mentioned that a more formally correct way to analyse the system is to consider an additional coordinate on the Poincaré section, since the total energy is not exactly constant but only controlled to be constant. Nevertheless, if the total energy control is fast enough to ensure that the total energy does not deviate far from its desired value the approximation of considering a constant energy level is reasonable. Due to the energy loss at the foot touch down and the nonlinearities in the dynamics, the fixed point on the Poincaré section, however, differs from the original fixed point of the SLIP model. Therefore, one of our future works will be to investigate how the resulting limit cycle and the corre-

sponding fixed point on the Poincaré section can be actively controlled. Moreover, we plan to investigate on the use of passive elastic components in order to reduce the control effort in the realization of SLIP based walking patterns.

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