Walking speed control through foot placement in planar bipeds

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1 Introduction

When humanoid robots are going to be used in society, they should be capable to walk at various walking speeds. It appears that foot placement is important to control walking speed. Here we present an algorithm to determine proper foot placement (FP) for control of the walking speed of planar bipeds with point feet. The algorithm is based on conservation of energy, taking into account energy losses at impact.

2 Biped model and walking speed control

We represent a planar biped as an inverted pendulum. Although this representation is not very accurate it is useful to gain analytical insight and generate trajectories for complex humanoid robots [1]. At a step, the pendulum origin is moved and its velocity is reset due to energy loss at impact, such that the total model can be written as impulsive system:

$$\begin{cases} \ddot{\theta} = \sin(\theta), & \theta_- \notin S, \\ \dot{\theta}_+ = -\cos(\theta_-)\dot{\theta}_-, & \theta_- \in S, \end{cases} \tag{1}$$

where θ is the orientation of the normalized inverted pendulum, and S is the impact surface. Subscripts $_-$ and $_+$ indicate states just before and after impact respectively.

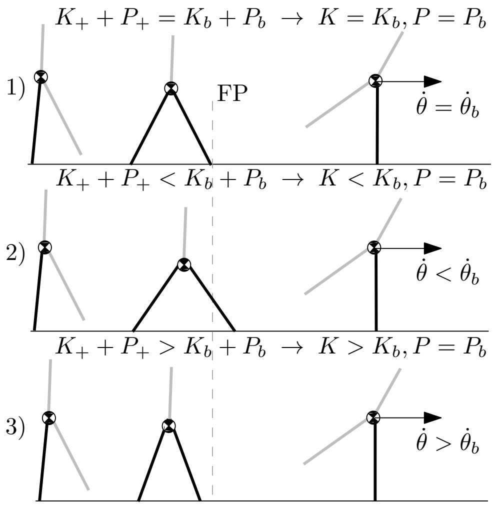

Figure 1: Schematic drawing of the relation between foot placement and walking speed. The kinetic and potential energy are K and P and the pendulum angular velocity is $\dot{\theta}$ ($_+$ are values just after impact and $_b$ desired values).

We define the desired walking speed as $\dot{\theta}_b$, the angular velocity of the pendulum at mid-stance, i.e. when the potential energy P is maximal. In this way, foot placement can be related with the resulting walking speed, see Figure 1:

1) The biped steps onto the FP point and it reaches the desired walking speed at mid-stance.
2) The biped steps after the FP point so that the walking speed at mid-stance is lower than the desired one.
3) The biped steps before the FP point so that the walking speed at mid-stance is higher than the desired one.

The model (1) is Lagrangian, so the sum of the kinetic energy K and the potential energy P is conserved during a step:

$$K(\theta_+, \dot{\theta}_+) + P(\theta_+) = K(\theta_b, \dot{\theta}_b) + P(\theta_b). \tag{2}$$

Solving (2) for θ_+ yields the desired location that indicates where the foot would need to be placed to exactly achieve the desired walking speed at mid-stance. At impact, the system dissipates energy, so the desired walking speed must decrease over subsequent steps.

3 Simulation results

The model (1) is implemented in simulation. At each time step we solve (2) for θ_+ and reset the model when $\theta = \theta_+$. The result of a simulation for various walking speeds is shown in Figure 2. The simulations show that the biped walks at the desired walking speed.

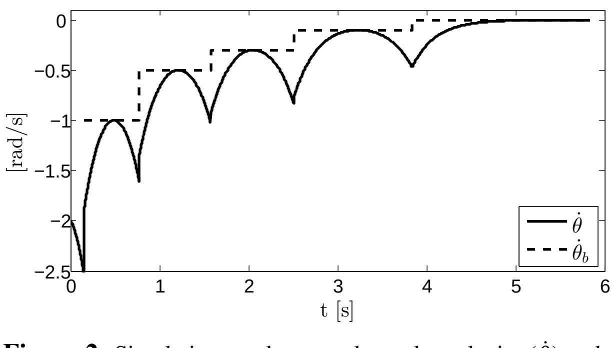

Figure 2: Simulation results: actual angular velocity ($\dot{\theta}$) and desired one at mid-stance ($\dot{\theta}_b$)

References

[1] T. Assman, P. van Zutven, and H. Nijmeijer. Qualitative validation of humanoid robot models by side-stepping experiments. In *IEEE International Conference on Robotics and Automation (ICRA)*, 2013.