Technische Universiteit Eindhoven University of Technology

Balance of humanoid robots by proper foot placement

Pieter van Zutven and Henk Nijmeijer
p.w.m.v.zutven@tue.nl

Introduction

When humanoid robots are going to be used in society, they should be capable to maintain their balance. Knowing where to step appears to be important to remain balanced. Here we present an algorithm to determine proper foot placement for balance of planar bipeds with point feet [1]. The algorithm is based on conservation of energy, taking into account energy losses at impact.

Biped model

We model a biped as a chain of N rigid bodies from stance to swing foot interconnected by revolute joints. The stance and swing leg swap immediately at the impact of the swing foot with the ground, so that the biped can be modeled as a system with impulsive effects:

$$\begin{cases} D(q)\,\ddot{q} + C(q,\dot{q})\,\dot{q} + G(q) = u, & \kappa(q) \neq 0, \\ \dot{q}_+ = \Delta(q_-)\,\dot{q}_-, & \kappa(q) = 0, \end{cases} \quad (1)$$

where $q \in \mathcal{Q} = \mathbb{T}^N$ is the state vector, $D \in \mathbb{R}^{N\times N}$ is the inertia matrix, $C\dot{q} \in \mathbb{R}^N$ is the Coriolis and centrifugal vector, $G \in \mathbb{R}^N$ is the gravity vector and $u \in \mathbb{R}^N$ is the input vector. The impact map is given by $\Delta \in \mathbb{R}^{N\times N}$ and $\kappa : \mathcal{Q} \to \mathbb{R}$ is the distance between the swing foot and the ground. Subscripts $_+$ and $_-$ indicate states just before and just after impact respectively.

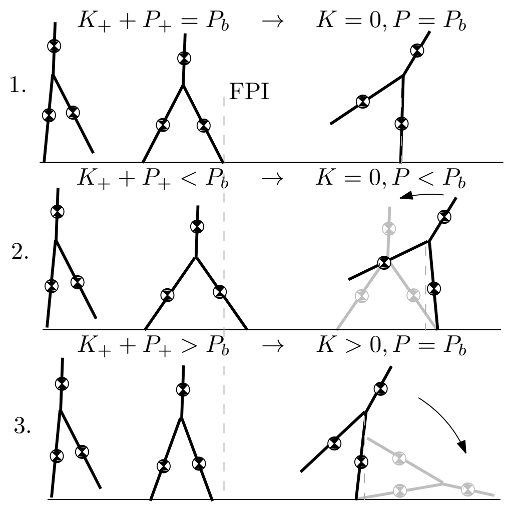

Figure 1: Schematic drawing of the relation between foot placement and balance. The kinetic and potential energy are K and P respectively and the potential energy in a balanced configuration is P_b.

Foot placement and balance

A balanced configuration is a configuration in which the center of mass of the biped lies exactly above its stance foot. A biped is in balance as long as it can still place its swing foot at a location such that it evolves to a balanced configuration, see Figure 1:

1. The biped steps onto the FPI point and it stops exactly at the balanced configuration.
2. The biped steps after the FPI point, does not reach the balanced configuration and falls backward.
3. The biped steps before the FPI point, does not stop at the balanced configuration and falls forward.

The desired foot placement for balance can now be found if we assume that energy is conserved after impact:

$$K(q_+,\dot{q}_+) + P(q_+) = K(q_-,\Delta(q_-)\dot{q}_-) + P(q_-) = P_b. \quad (2)$$

Solving (2) for q_- yields the desired location that indicates where the foot would need to be placed to balance the biped if the impact were to occur in the next instant.

Simulation results

We modeled a five link planar biped according to (1). We simulated the model and at each time step we solved (2) for q_- and used this as reference for a feedback tracking controller. We let the biped step before the FPI point (case 3.) such that a balanced walking gait is achieved as can be seen in Figure 2.

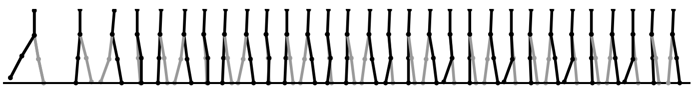

Figure 2: Simulation results: the biped continuously steps before the FPI point so that a balanced walking gait is achieved.

This simulation shows promising results for balance of humanoid robots through proper foot placement. Currently we are planning to verify the algorithm experimentally on our humanoid robot TUlip.

References

[1] P.W.M. van Zutven, D. Kostić, and H. Nijmeijer. Foot placement for planar bipeds with point feet. In *Proceedings of IEEE ICRA*, 2012.