Heel to Toe Gait for Efficient Bipedal Walking

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Motivation

Typical robotic bipedal walks tend to be relatively inefficient, which causes problems in motor wear and overheating. One of the more prominent reasons for this is due to the constant bend in the knee of the support leg while walking, which requires continuous actuation at the knees in order to support the weight of the robot. Straightening the knee is not a simple task, since typical walks attempt to keep the feet parallel to the ground at all times with the torso at a constant height, making a knee bend necessary in order to complete a stride. In addition to this, most inverse kinematics derivations fail in areas where the knee is straight or almost straight, since small changes in foot position can create very large changes in the knee angle, which in turn will stress motors greatly and create further inefficiency.

Although there are many possible solutions to this problem, here we suggest that the best way to achieve a straightened support leg is to walk as humans do — by planting your heel into the ground to begin a step and lifting off with your toe at the conclusion of a step. This style of gait has several other advantages, including a long double support phase which helps to improve stability, and a high degree of efficiency in general[1].

Implementation

We divide the walk into three phases:

- The *swing* phase starts just as the swing foot's toe lifts off the ground, and ends as soon as its heel hits the ground.
- The *rock* phase sees the robot switch its weight from one foot to another. Both knees aim to be straight during this phase. By the end, the front foot becomes flat and the rear foot will lift its heel if necessary.
- The *lift* phase sees the rear foot lift its heel and move the knee joint forwards, keeping its toe on the ground. This acts to extend the double support phase and to begin the swing phase more naturally.

Motion during these phases is controlled in a variety of different ways in order to overcome inverse kinematics issues when the knee is fully extended.

Most inverse kinematics is controlled by interpolating the x and z position of the toe or heel and the *angle* of the foot relative to the torso, calculating the necessary joint angles in the hip, knee and ankle in order to achieve this.

When the knee is fully extended, we do not control one of either the z or the *angle* components of the foot position and allow this parameter to be determined by the others instead.

During the *lift* phase, we control the knee joint angle of the back foot instead of the foot angle in order to prevent large knee angle velocities from occuring, and to control the initial knee velocity for the swing.

During the *swing* phase, instead of controlling the foot's position we directly control joint angle values, and provide an initial, intermediate and final set of angle goals with initial and final angle velocities, interpolating using a 5th degree polynomial.

These measures ensure smooth movement throughout the walk, which is important for efficiency.

Stabilisation is not the focus of this project, but we are using a combination of an open loop ZMP targeting model, and adjusting the ankle and hip joints linearly with sensor inputs.

Demonstration

For the Open Challenge demonstration we will have a short presentation about the walk's key features, and display the walk in action on a Nao.

[1] *In 1998, Garcia et al. produced a passive-dynamic walker which moved with a heel to toe gait while being powered by nothing but gravity, demonstrating how little energy the gait requires.*

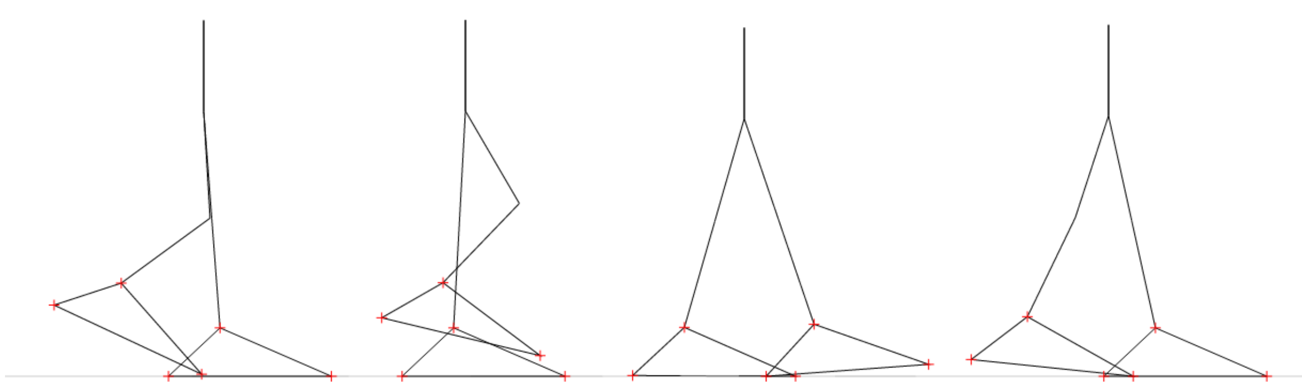

Figure 1: From left to right, we see the walk at the beginning of the swing phase, midway through the swing phase, at the end of the swing phase, and after the rock phase. Notice that the support foot's knee is always fully extended.