**Swing Leg Dynamics**

The goal is to produce simple models where the swing leg swings above the ground with some clearance, instead of swinging through the ground. Inspired by the Fast Runner Robot (Jerry Pratt).

**SLIP Model**

Spring Linear Inverted Pendulum Model. The simplest runner comprised of an inverted pendulum on a spring that bounces on the ground and then jumps into the air for aerial phase before the next step. This paper talks about the SLIP model and develops it into a different model as well:

<http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5175424&tag=1>

**Swing Model**

Models the swing leg of a SLIP model as a point mass with 2 springs (hip & leg).

It is assumed that the swing foot mass is equal to zero in the limit, such that it has no effect on the stance leg and pelvis. Therefore, limit cycles are taken directly from the SLIP model to be used as input in the Swing Model. The SLIP limit cycles affect the swing foot in two ways:

1. The force exerted by the leg spring on the swing foot depends on the position of the pelvis
2. If the class property sephips = 0, then the force exerted on the swing foot by the hip spring depends on the angle of the stance leg of the SLIP model.

For effect 2), if sephips = 1, then the force of the hip spring is proportional only to the difference between the swing leg angle and the set point. This could be thought of as the hip pulling against a torso which is infinitely heavier.

If sephips = 0, then the fact that the hip force also depends on the stance leg angle means that that the speed of the swing will be faster. As the swing leg kicks through, the stance leg is also rotating in the opposite direction, which means there is a larger angular distance between the two legs than compared to measuring the swing leg angle against vertical. This results in a greater force being exerted by the hip spring on the swing leg. The hip spring still has no effect on the stance leg in this case since the stance leg angle is entirely determined by the SLIP dynamics.

The simulation of this model starts at toe-off, when the swing foot is just coming off the ground. This is different than most models which begin with heel-strike. Since before the foot comes off the ground, it has zero velocity, the foot has an initial velocity of zero at the beginning of the simulation. However, applying an impulse at the start of the simulation allows more limit cycles to be achieved and may be lead to insights about the system.

For example, an impulse only along the direction of the leg is analogous to yanking a mass on a string along that direction. The coefficient of restitution determines how much velocity the impulse will impart. A coefficient of 1 imparts a velocity to the foot twice that of the separation velocity between the pelvis and swing foot.

This example with a coefficient of 1 is located in SavedGaits/Swing/Swing\_yank1.mat and a parameter study on the coefficient of restitution is located at ParameterStudies/Swing/yankimpulse.mat. Note that the class property impulsecoeff corresponds to the coefficient of restitution + 1 according to this nomenclature.

**RetractKneeSwing Model**

Models the swing leg as 2 rigid legs (thigh & shank) and 2 springs (hip & knee). This has the same goal as the Swing model. Its goal is to explore how the rigid body mechanics of having two segments helps/hurts the ability to swing the leg above the ground to the next step.

A characteristic of this model is that as the hip spring pulls the thigh forward, the rigid body dynamics cause the shank segment to rotate upwards, allowing it to clear the ground easily during mid-swing. In contrast to the Swing model, where either an impulse or a leg spring with a set point close to the pelvis is required to clear the ground, in this model, the double pendulum dynamics naturally tend to swing the foot upwards. These dynamics are aided by the hip spring pulling on the thigh, causing the foot to swing up even more.

If the thigh does not rotate backwards towards vertical at the end of the step, then the shank will go through the ground as it swings to be a straight leg at the end of the step. This could theoretically be avoided if the shank was allowed to rotate CCW and pass through the thigh.

If the thigh does rotate back towards vertical at the end of the step (as human data suggests), then the knee has the ability to hyper extend and then land straight without going through the ground. Of course, humans do not hyperextend their legs to run (by much anyways). The swing leg energetics in human data may suggest that the knee does not behave quite like a spring. Instead, during late swing the knee may instead be used to keep the knee fully extended without moving much in preparation for landing on the ground when it will flex. This behavior may also be accomplished in part by range of motion limitations of the knee which may serve as a hard stop to hyperextension without requiring that much activation of muscle.

Another area of interest is the ratio of shank to thigh mass. At one extreme, if the mfoot << mshank, then the knee spring & inertial forces due to the foot will have no effect on the thigh. This relationship should be investigated further perhaps through a parameter study.