Biped Energy Control For Balance and Walking

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I. SUMMARY

We present work towards compliant control of humanoid balance and walking. We make use of an extended version of the Linear Inverted Pendulum Model (LIPM) [1] that includes the effects of two feet. The model explicitly defines the dynamics of single support and double support phases. Using a Lyapunov function based on a desired energy, we can generate stable controllers that can achieve any desired energy, regulating to a point or to a limit cycle. These controllers are applied to a torque-controlled humanoid robot resulting in improved balance.

II. INTRODUCTION

Humanoid robots are complex systems that are often studied using simple models such as the LIPM. Often, this model is used in combination with desired foot trajectories. A trajectory for the center of mass is created so that the center of pressure, or zero moment point, is always within the base of support.

We use an extension of the LIPM that includes the robot feet and double support phase dynamics. This allows us to better understand the complex problem of humanoid balance and walking using a simple, intuitive model. Rather than preplanning trajectories, we would like controllers that stabilize the system from unknown errors. We are interested in two types of stabilization: 1) Avoid falling over after a large impulse and eventually come to rest, and 2) Walk with a desired frequency, or energy, converging to a cycle.

III. METHODS

We begin with an extension of the LIPM that includes two feet, shown in Figure 1. We include the forces and torques at the feet in our formulation. In single support, the system behaves just like the LIPM. However, in double support, the system is over-constrained. This problem is common to all biped robots, but our simplified model results in a simplified solution.

To control the system, we define a desired energy, similar to the "orbital energy" that many have used in the past [2]. Using a Lyapunov function of the form, $V = 1/2\left(E_{\text{desired}} - E\right)^2$, we can derive a nonlinear controller that stabilizes the system to any desired energy. If the desired energy is zero, the system stabilizes to a point, otherwise it will converge to a limit cycle. For the coronal plane, we use an energy that results in an ellipse, causing the system to oscillate back and forth. In the sagittal plane, we define a hybrid energy that is periodic but always moving forward.

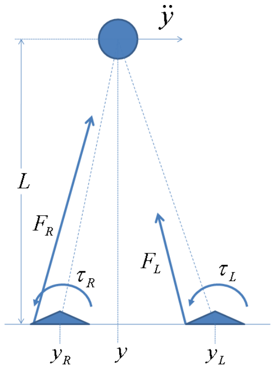

Fig. 1. Two-Legged Linear Inverted Pendulum Model

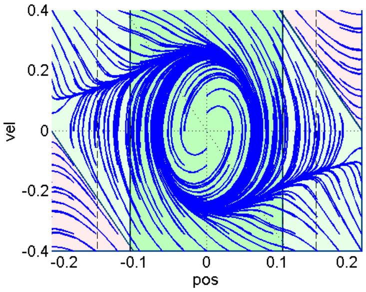

Fig. 2. Controlling the energy in the coronal plane causes the system to converge to a limit cycle

IV. RESULTS AND DISCUSSION

The nonlinear energy controller successfully stabilizes the system to a cycle defined by the energy, as shown in Figure 2. Notice that the policy is globally stable within the "stability region" [3]. This same controller also works for the sagittal plane and forward walking.

The energy controller has been applied to a torque-controlled humanoid robot resulting in improved balance in the coronal plane. Currently we do not consider a foot placement strategy, though it is not difficult to extend the model to include that capability.

REFERENCES

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