Effects of Open-Loop Leg Forcing in Rotary and Radial Directions

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1 Motivation

In legged locomotion, the active forcing contributed by the leg can be considered to act in rotary and radial directions relative to the leg. Rotary forcing acting perpendicular to the leg, such as forcing due to hip torque, and radial forcing acting in the direction along the leg from foot to hip, are both present in animal locomotion. Given that these directions are orthogonal, simple rotary and radial leg forcing could be considered as basis functions of leg forcing. A systematic comparison of these types of actuation on the dynamics and energetics of legged locomotion would be valuable for the field of legged robotics, and for developing testable hypotheses regarding human and animal locomotion.

2 State of the Art

One method to study legged locomotion is through modeling and analysis [1]. Recently, an increasing number of models of legged locomotion with realistic actuation and damping have been developed, many based upon extensions of the simple Spring-Loaded Inverted Pendulum(SLIP) model. Inspired by RHex [2], a robot that is capable to walk and run robustly on various terrains, the Clock-Torqued Spring-Loaded Inverted Pendulum (CT-SLIP) [3] was developed with a clock governed hip torque and leg damping. It is fully asymptotically stable has been used to explain some animal locomotion behaviors. Similarly, a model called Torque-Damped Spring-Loaded Inverted Pendulum (TD-SLIP) [4] with hip torque is able to demonstrate full asymptotic stability. More recently, a model called the Hip-actuated Spring-Loaded Inverted Pendulum (Hip-actuated SLIP) [5] with hip torque throughout the stance was developed to understand the intrinsic effects of hip torque on locomotion stability. It reveals the fundamental role hip torque plays in stabilizing legged locomotion.

Radial forcing is another major locomotion actuation scheme, and yet it is not well understood how the effects of radial and rotary forcing differ. An important next step is to systematically study and compare the effects of rotary and radial forcing on locomotion stability and energetics.

3 Own Approach

To explore the dynamical effects of rotary forcing (hip torque) and radial forcing, two models called the Rotary forced Spring-Loaded Inverted-Pendulum (Rotary-forced-SLIP) and the Radial forced Spring-Loaded Inverted-Pendulum (Radial-forced-SLIP) were developed. A constant hip torque is applied from touchdown to mid stance for the Rotary-forced-SLIP, while a constant radial force is applied from mid stance to liftoff for the Radial-forced-SLIP. Their respective flight dynamics remain the same as the canonical SLIP: just reset the leg to a constant landing angle while the mass undergoes ballistic motion. These two models are then numerically integrated and analyzed to compare their respective stability and energetic cost of locomotion.

4 Current Results

Energetic efficiency and stability are among two of the most important performance metrics of legged locomotion. We have found that, overall, the rotary based forcing model Rotary-SLIP is better at stabilizing legged locomotion. However, radial based forcing, as in the Radial-SLIP model is found to be more energy efficient. To make this comparison we focused on comparing the achievable locomotion of the two models overall since they can operate over different regions of the model parameter space.

5 Best Possible Outcome

We plan to combine rotary forcing (hip torque) and radial forcing in one model and determine if it produces one mechanism that has both good stability and energetic efficiency. The expected outcome is that a combination of rotary and radial forcing can yield legged locomotion that is more robust to small and large perturbations and more energetically efficient than when either forcing method is present alone.

Acknowledgments

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References

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