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Series Elastic versus Parallel Elastic Actuators in Hopping Robots

Marion Anderson[1], Taylor McLaughlin[2], Shai Revzen[3]
[1]ECE, [2]University of Michigan, Ann Arbor, MI

Introduction

For hopping robots in the 3kg range, high hop-to-hop energy restitution has not been reported [1], [2]. We built several hopping robots based around elastic energy storage in high coefficient of restitution spring steel leaf springs to explore means of improving energy efficiency in a hopping gait. We present lessons learned from hopping robot design when using both series elastic and parallel elastic actuators. With series elastic actuation our best restitution was 11.2±2.2%; with parallel actuation using the same springs and motors our best restitution was 49±5% .

Methods

We collected data at 100Hz using a reflective-marker-based motion tracking system (Qualisys). The average height of the markers at the ends of the spring "feet" marked height above ground.

We computed restitution by dropping the robot and calculating the ratio between drop height and the height of the following bounce. We zeroed measured heights by subtracting the height of the robot at rest on the ground. We measured this reference height at the start of every trial.

We performed three different trials to examine the effects of spring preloading on restitution: first with the springs unbent, second with the motors holding an angle of 20 degrees from the robot frame horizontal, and third with the motors holding an angle of 30 degrees from the robot frame horizontal.

Results

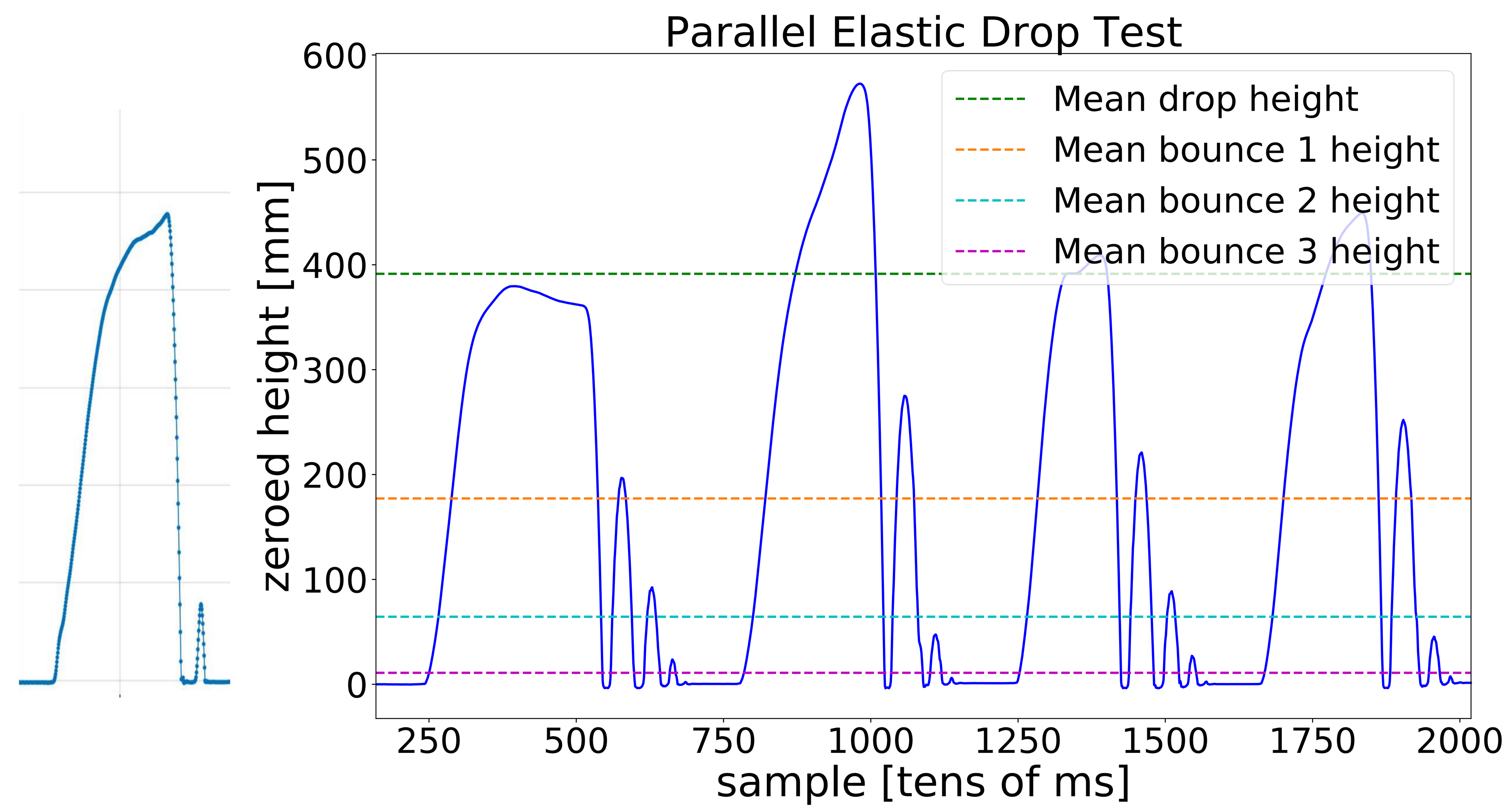

Fig. 1. A comparison of series elastic actuator restitution (left) versus parallel elastic actuator restitution (right) on our hopper. The left plot is unitless; it has been scaled to showcase the difference between series elastic and parallel elastic restitution on this robot.

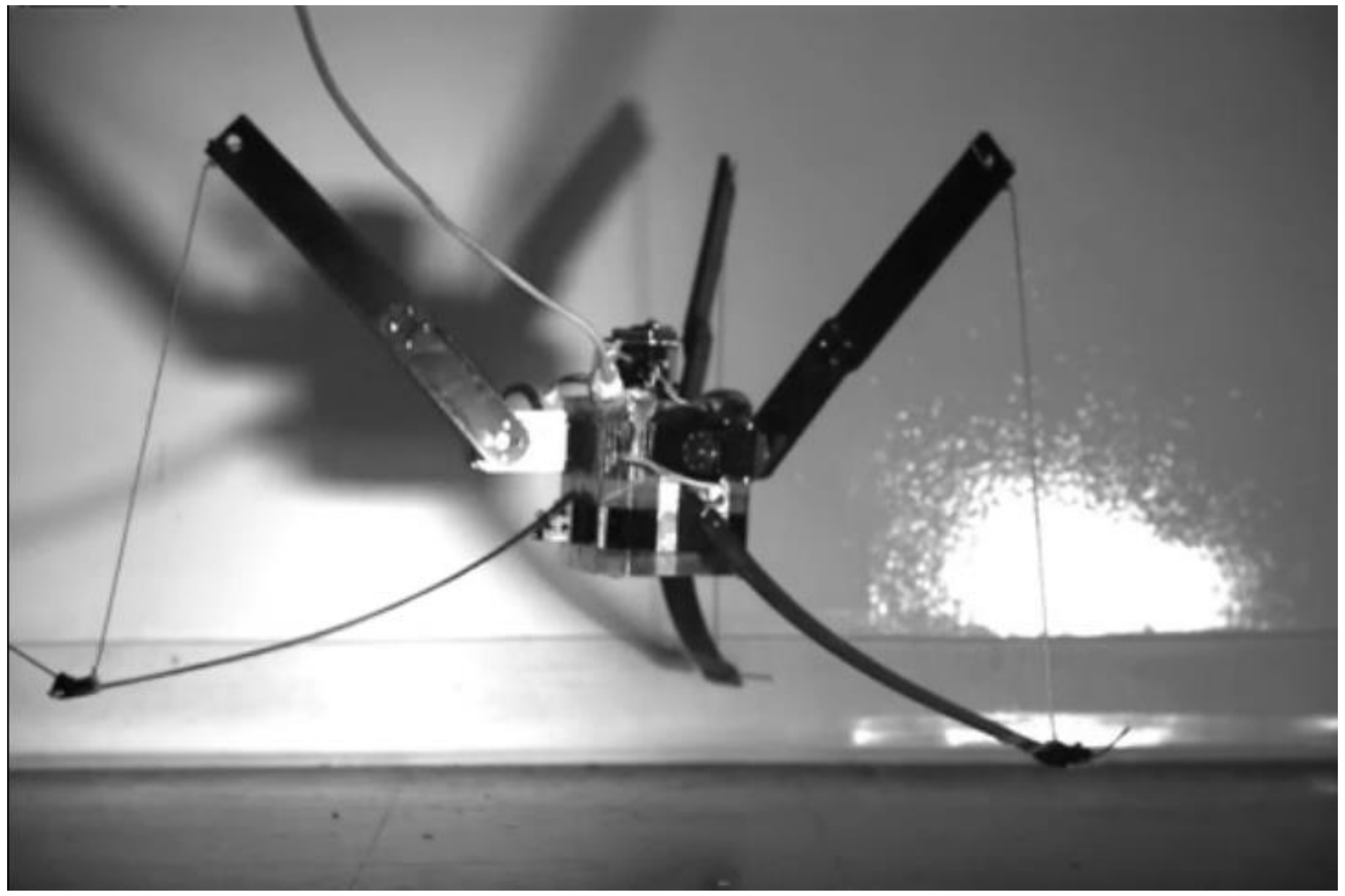

Fig 2. Image of hopping robot with preloaded springs.

Preloading Comparison

We wanted to see if preloading the springs would result in more efficient conversion of kinetic energy to elastic potential energy. Commanding the motors to hold a setpoint angle from the robot frame horizontal preloaded the springs.

Without preloading, our hopper exhibited 25±3.6% restitution. The 20-degree and 30-degree trials had restitutions of 49±5% and 43.5±5% respectively.

Discussion

Despite the ability to develop arbitrary control laws that mimic conservative systems using techniques like passivity-based control or inverse dynamics, most commercial motor controllers operate in specific modes, e.g. position or torque control. In these modes, ground collisions tend to be treated as disturbances, which damps out any stored energy.

When building hopping robots using commercial controllers with significant energy restitution, a parallel path for energy storage, such as a parallel elastic element, can significantly improve restitution.

References

[1] Okubo, et. al., "Design of a jumping machine using self-energizing spring," IROS '96, vol. 1, pp. 186–191, 1996.

[2] Sayyad, et. Al., "Single-legged hopping robotics research - a review," Robotica, vol. 25, pp. 587–613, 2007.

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