Serial Elastic versus Parallel Elastic Actuators in Hopping Robots

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I. INTRODUCTION

Hopping offers unique advantages for locomotion over rough or intermittent terrain. The ability to go over obstacles instead of around them would open new path planning options for terrestrial locomotion. A major challenge to making hopping locomotion feasible is energy efficiency because hopping requires sudden releases of energy in order to leave the ground. 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 serial elastic and parallel elastic actuators. With serial elastic actuation our best restitution was 11.2%; with parallel actuation the same springs and motors gave $49 \pm 5\%$.

II. RESULTS & BRIEF DISCUSSION

We sought a high restitution, multi-legged hopping robot to explore the Event-Selected Systems (ESS; [3]) that appear when a 3-legged hopper impacts the ground. For the ESS dynamics to play a role across such a multi-contact collision, the collision cannot be plastic – velocities should be mostly preserved; ideally, a significant portion of the kinetic energy should be restored. We initially attempted to build a hopping robot based on a direct-drive Minitaur robot leg (similar to [4]) which could theoretically be programmed for a conservative Hook-spring force law. With and without an added physical coil spring, this exhibited little to no restitution. We then built a series elastic hopper with geared motors (Robotis Dynamixel MX106) in series with spring-steel cantilever legs. This exhibited a restitution of 11.2% using the best of several designs. Finally, we developed a parallel elastic actuation with the same motors and springs, and a cable system allowing the motors to preload the springs, giving a restitution of $49 \pm 5\%$.

Our inability to achieve restitution with the direct drive brushless Minitaur legs suggests that the poor restitution of the serial elastic geared-down design was not itself a consequence of gearing, as is assumed by some. Instead, it seems that the electrical motors themselves are at fault.

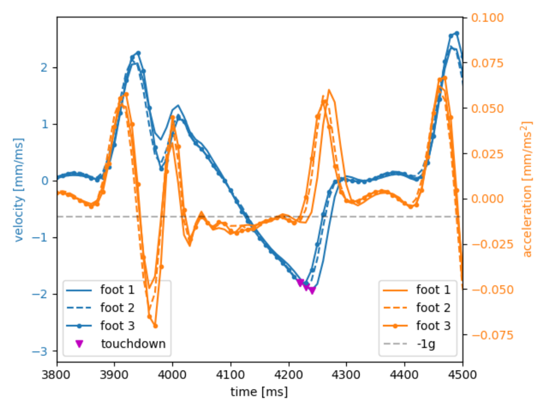

Fig. 1. A touchdown sequence of our 3-legged hopping robot, showing vertical foot velocity (blue) and acceleration (orange; corresponding line type). We have also marked $-1g$ (horizontal dashed black), and the moment of touchdown for each foot (triangle).

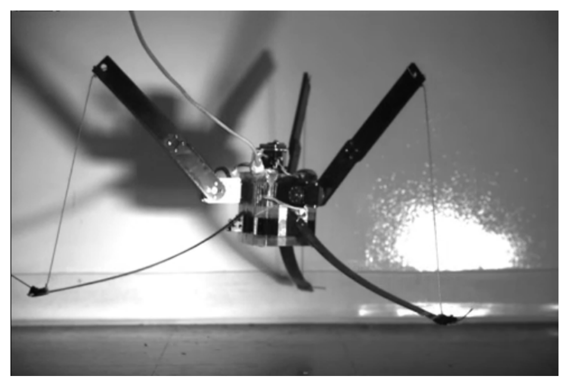

Fig. 2. Image of robot.

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