Leg Stiffness Control for Robot Running

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SUMMARY

The Electric Cable Differential Leg is the fourth in a series of machines studying the role of compliance in legged locomotion. The ECD Leg is the basis for the monopod named Thumper, as well as the biped named MABEL. Our engineering goals were to develop a capable and efficient running and walking machine, and our scientific goals were to determine the energetic costs of varying only the leg stiffness during a running gait. I will present pictures, videos, and experimental data for the planar hopping monopod Thumper, and demonstrate that the leg stiffness has an energetically optimal value.

INTRODUCTION

Although biomechanics studies show that animals adjust leg stiffness "on-the-fly," there are many aspects we do not understand - for example, how leg stiffness is adjusted, why it is important, or what determines the chosen leg stiffness [1]. In addition, animal behavior is not necessarily optimal for robots, because different limitations and abilities apply to motors versus muscles.

To explore the role of compliance in legged locomotion, I have designed and built two benchtop actuators, two planar monopod hopping robots, and a planar biped robot. Along with the scientific goals of understanding compliance in legged locomotion, an important goal in building these machines is to refine robot designs for robust, efficient operation in real-world environments.

The planar monopod Thumper successfully runs using passive dynamics as an integral part of the control system [2]. Conceptually, its operation is similar to the Raibert hoppers or the ARL Monopod II; one motor controls the leg length with a large spring acting in series, while the other motor controls leg angle, much like a common mass-spring running model. However, the engineering approach is very different from earlier machines. Thumper uses electric motors, steel cable drive transmissions, fiberglass springs, and an aluminum and carbon fiber frame. In addition, it has knees that bend like an animal, rather than prismatic joints like a pogo stick.

Experimental Methods and Results

In experiments with Thumper, we varied the leg stiffness through a range of spring constants by swapping springs, while maintaining all other aspects of the running gait constant. We measured the mechanical work done by the motors, and determined that there is an energetically optimal leg stiffness. As leg stiffness increased or decreased farther from the optimal value, the mechanical work done by the motor increased.

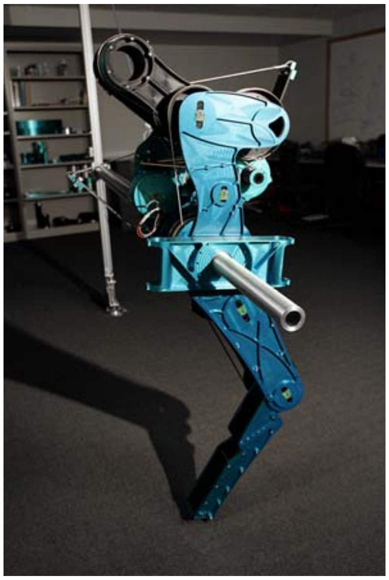

Figure 1: Thumper, a planar hopping monopod

While changing the leg stiffness on Thumper required us to physically remove and replace the springs, our earlier prototypes controlled leg stiffness on-the-fly through co-contraction of antagonistic springs. This online stiffness adjustment allows the robot to maintain an optimal leg stiffness at all times. However, there is an energetic cost – antagonistic springs store almost an order of magnitude less energy than a single spring in series.

Discussion

Physical springs are very important for a running gait, and choosing an optimal stiffness affects the energetic efficiency. In comparing methods for adjustment of leg stiffness, our experience suggests that active control can successfully be used to adjust the behavior of the springs. Furthermore, the energetic cost of using active control may be relatively small compared to the cost of storing energy in antagonistic springs.

REFERENCES

1. Farley, C.T. & Gonzalez, O., *Journal of Biomechanics*, 1996, 29, 181-186
2. Hurst, J.W., Chestnutt, J.E., & Rizzi, A.A., *IEEE Robotics and Automation Magazine*, 2008, *September*, 42-51