Energy Recycling Actuators for Exoskeletons & Walking Robots

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Summary

Actuator mass and power consumption are limiting factors in walking robots and exoskeletons. Utilizing recently developed low power and lightweight electroadhesive clutches [1] we propose an Energy Recycling Actuator (ERA) to overcome these issues. The proposed system uses an array of elastic elements for energy recapture and force generation. The configuration of each elastic element can be independently controlled through two electroadhesive clutch pairs allowing for modulation of device stiffness and variable force output. We discuss optimization based approaches for design and control of the proposed system.

Introduction

In many mobile robotic applications power consumption requirements in actuators greatly limits the feasibility of untethered systems. This is true even when negligible positive mechanical work is done by the robot on its environment as is the case for walking robots. Recent state of the art biped and quadruped robots often have run times often less than 2 hours.

For zero net work tasks, such as raising and lowering an object, or negative net work tasks, such as walking down stairs, as no work is being done on the environment it is theoretically possible to act in a controlled way with no energy costs. This is demonstrated for example by passive dynamic walkers which rely on carefully designed linkages for stability. The limiting feature of most passive dynamic systems however, is that they cannot be actively controlled. The ERA makes use of passive elements (springs) but its configuration is controlled through engagements and disengagements of clutches which dictate its force output and effective stiffness. As a large number of clutches can be controlled at less than 1 W of total power consumption we can achieve active control of a mostly passive dynamic system with low energy costs. Augmenting the ERA with a small motor allows for finer force control and allows for operating in zero or slightly positive work environments such as an active ankle prosthesis.

Design

The ERA consists of a set tension springs each connected to 2 clutch plates. This allows each spring to be clutched to the actuator frame, holding its energy level, or clutched to the actuator output, transmitting a force. As the tension springs only pull in one direction, bidirectional actuation can be achieved by using antagonistic ERAs or by adding a bias force in the other direction. By using springs that hold different levels of force, a wide range of force outputs can be achieved through different combinations of clutch engagements.

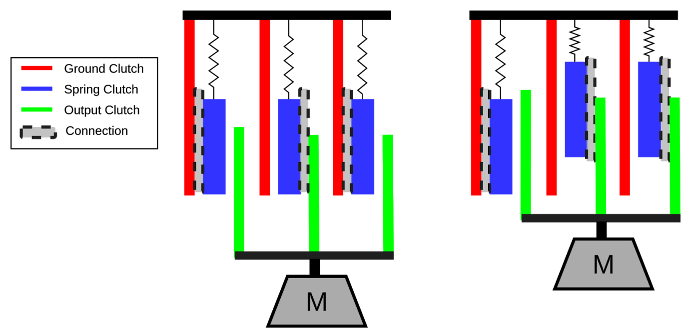

Figure 1: *Example energy recycling actuator configurations. Left:1 spring is attached to the output loaded with a mass and the system is in equilibrium Right:A second spring is attached to the outputand the mass is raised.*

Control Simulation

Control for the ERA amounts to choosing which clutches should be engaged at each time step. As such, path planning becomes a high dimensional combinatorial optimization problem that is not easily handled by classical control theory. We present some preliminary results for control strategies based on optimal control and reinforcement learning that have performed well in simulation.

Acknowledgments

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References

[1] Diller, S. B., Collins, S. H., Majidi, C. (2018) *The effects of electroadhesive clutch design parameters on performance characteristics*. Journal of Intelligent Material Systems and Structures, 29:3804-3828.