Team Name Group Proposal

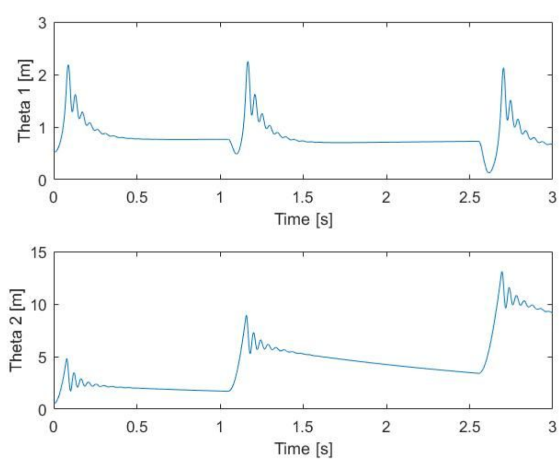
1. Introduction and Principal Extraction

The use of a series elastic actuator in the two-bar jumping leg will help us understand the dynamics of pretension in muscles. When animals jump they tense their legs prior to takeoff and store elastic energy in their muscles helping them increase force production over the jump acting both mechanically (stretch) and electrochemically. Given equal maximum input torque from the motor, we hypothesize the addition of the spring will increase time integrated torque output over the course of the jump and lead to a higher jumping height.

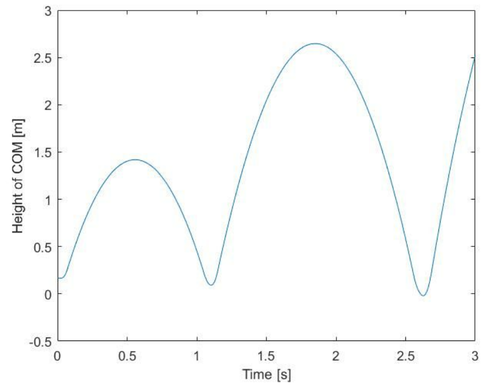
Another non-biologically inspired hypothesis about the performance advantage of a spring in series configuration, especially that of a rather compliant spring, is that we may be able to slightly lessen the rate that the output torque diminishes (with speed) over the course of the jump. Although electric motors are highly speed dependant, springs are practically independent of speed. During the course of the jump if the motor made to maintain its maximum speed limited torque throughout, as the torque output of the motor drops off with speed, the spring will maintain the torque prescribed by its current strain state, its extension being limited by the system inertia. Effectively this means the motor will slow to whatever speed at which it is able to produce the strain-prescribed torque while the output shaft accelerates at that prescribed torque, but possibly a higher speed than would be producible by the motor at that speed. But the motor need not ever be at full halt. Another interpretation of the effect is that the motor is allowed to maintain a lower average speed over the course of the jump (meaning higher torque) for the same angular displacement of the output shaft and temporal window.

The effect is not bio-inspired, but its intentions are related to overcoming a current mechanical design limitation allowing potentially more natural dynamical motion.

2. Dynamical Model



The dynamic model is similar to the jumping leg from Homework 4. The leg is modelled as a two bar linkage with the hip and the foot constrained to the same axis. Instead of a simple electric motor to drive the leg, a series elastic actuator is connected at the hip. The motor output shaft is connected to one end of a low inertia torsional spring. The other end of the spring is connected to the hip joint of the leg. The displacement of the hip is denoted as theta 1 and the displacement of the motor shaft is denoted as theta 2. Both angles are relative to the horizontal. The spring has a small component of rotational kinetic energy, but has negligible mass relative to the system. The spring potential energy is included in the lagrangian as well as the generalized force from the internal damping of the spring. To capture the dynamics of the series elastic actuator, we will have to choose the stiffness of the spring. The internal damping of the spring will be based on its material properties and can only be increased if we add friction to the system. A clutch system will be implemented to allow the spring to be pretensioned while the leg is in the air. The clutch will be activated once the leg has reached its landing configuration, which will be similar to the initial conditions on the system.



3. Experimental Setup

A. Mechanical design

To make the experimental hardware, we will construct the leg as informed by the dynamical model. The legs will be made of two bars of equal length and connected by a pin at the knee. The two bars will be constrained to a post so the leg can only jump vertically. The foot will be connected to the post with a pin and slider so that the foot makes contact with the ground at the same point every jump. The motor will be connected to the post and provide the input torque to the system. The spring can be made out of an elastomer, a torsional spring, or a flexure.

Each state variable in the system will need to be measured with a sensor. A photodiode on the hip and an alternating black and white pattern on the post will measure the vertical displacement of the leg. An encoder on the motor will measure theta 2. To measure theta 1, the displacement of the spring must be recoded. A strain gauge would be paired with the elastomer, while an encoder would be used with the torsional spring or flexure. Given these inputs we will be able to control the jumping of the leg.

The primary mechanical design challenge will likely be the motor, elastomer, clutch assembly. Clutching at this size is a less routine challenge, though in no-ways uncharted. Small machinery and controls equipment (printers, cameras etc) use clutches from time to time to regulate power transmission. Because of the high speed switching low weight requirement we will certainly employ some sort of electro-magnetic clutch. Entirely magnetic clutches exist where the entirety of the mechanical power is transmitted magnetically. However a magnetically actuated spring-clutch will probably suffice. Sources certainly exist[1] but finding a suitably single purchase supplier will demand a some degree of search. We are also open to suggestions on simple miniature clutching mechanisms.

The clutch exists to allow the motor to more effectively contract the spring before landing. During flight when the leg has reached a landing configuration, theta 1 will be fixed with the clutch while theta 2 is set by the motor torque input. The pretension will be held until the moment of landing when the clutch is released allowing the leg free interaction with the spring and ground.

[1] http://www.tinyclutch.com/magnetic-clutches.htm

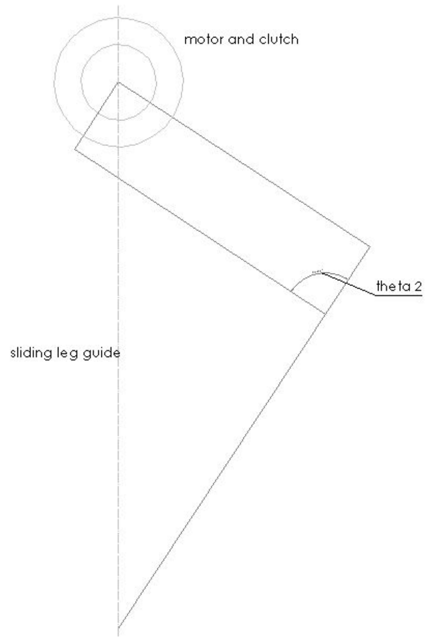


Figure 1: Basic solidworks sketch of jumping leg architecture.

B. Fabrication

Virtually the entire robot excluding fasteners and actuators will be 3d printed from the leg struts to the motor and clutch mounts. The challenging part of fabrication is interfacing with the spring element. If the spring is a metal the ends will almost invariably be small and pose some challenge in fixturing. If the spring is elastomeric which is more likely, there exists fewer well defined ways of securing it at either interface. Hopefully both interfaces will be 3d printed plastic with some pin centering feature and we will be able to find the right epoxy with which it can be reliably fastened.

C. Control Approach

The dynamical model presented above has shown that we have added a new state to the system. We have included a sensor, like a strain gauge or an encoder, in order to measure this and keep the system fully observable. To prove controllability of this nonlinear system, we linearized the equations of motion for the system while it is on the ground. We then computed the Kalman controllability criterion and showed that this matrix was full rank, as expected (implemented as a function in our matlab code). It then naturally follows that the system is underactuated when it is in the air, although we just want to keep the leg position stationary.

We will then use torque control on the output of the motor to drive the system through a sequence of states generated via trajectory optimization. Since the goal of the experiment is to perform the highest possible jump, we will formulate our optimization as a minimization over the negative of vertical height of the jump, similar to the fourth PSET problem. Once the leg leaves the ground, we will do a simple full state feedback controller to keep the leg and spring angles constant along the trajectory in the air.

We would like to verify our performance by measuring the center of mass trajectory and comparing it to the simulation of the dynamical model. We can do this by putting easily identifiable markers on the leg and then simply track the movement of these with a camera at a fixed distance away from the experimental setup. We can then interpolate the movement of the leg COM by tracking these features.

If time allows, we would then like to take the experiment to a series of jumps (2 or more). This will require a control law that not only attempts to keep the motor angle and spring angle constant, but also start the pretensioning as the legs gets close to the ground. It may be necessary to add another sensor so that we can add this anticipation of impact to the overall control policy.

4. Next Steps

A. Outline of time management

In this section, we will try to map out the distribution of as deliverables for each lab meeting.

November 1st	First meeting, discuss proposal, current design sketch, and simulations
November 8th	Develop controller and motor simulation, purchase hardware, possibly assemble
November 15th	
November 22nd	Testing and validation of model/hypothesis

B. Task Delegation

In this section, we list the individuals who will be responsible for each section of work. Even though each member will work on all the aspects of the experiment, the ones listed can be contacted if there is comments or concern on that aspect of the project.

Dynamical Model	Design and Fabrication	Sensors and Control
Dave	Abe	Luke