2.74/2.740 Team Project Proposal

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1. Title

Horizontal Distance Jumping from Rest in a 3-DOF Leg With Ankle Movement

2. Motivation and Background

After coming together for the team project proposal, we realized that all four individual proposals were focused on studying lunging or jumping. When researching kangaroo jumping, we noticed that kangaroos flex their ankles to launch themselves off the ground and began wondering whether their ankles provide additional lunging force . From a standing position, kangaroos are able to leap about 25 m. horizontally and jump 6 m. high. Based on the videos, it seems that kangaroos can achieve the large horizontal leaps by changing their initial stance, and leaning their body weight forward by flexing their ankles.

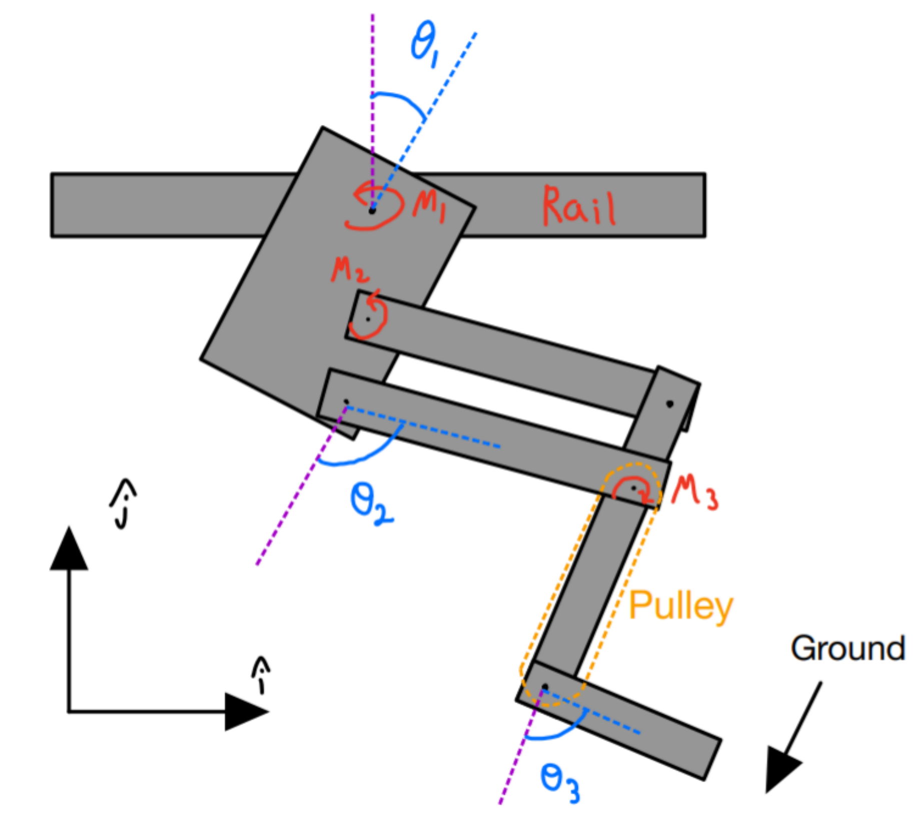
For the bio-inspired robotics project, we will examine the effect of an added DOF to a jumping robot to its horizontal and vertical reach. The main hypothesis we will test is: adding a DOF to a robot leg (in the form of an 'ankle') will increase the horizontal and vertical movement achieved by jumping or leaping from a standing position. We will use the controller methods used in the course for the simulation and hardware testing, and expect to conclude that a 3DOF leg will achieve a larger horizontal and vertical reach than a 2DOF leg can.

3. Experimental Setup

3.1 Hardware Setup

To test our hypothesis we will be using a 3 DOF motorized leg. The leg will be an extended version of the 2 DOF leg that's been previously used in lab with an extra link attached to the end. The third DOF will be driven by a pulley in the leg by a motor that is attached at the previous joint. The linkages will be thicker to accommodate for the added weight of the pulley motor in the leg. The other two motors will be placed at the hip to reduce the force moment on the leg. Each linkage will be 3D printed following the CAD files from the lab leg as a baseline. Nuts and bolts will secure all the linkages together in the assembly. The motors used will be the ones from the 2.74 lab kits along with the MBED microcontroller to operate the controls algorithms and motor commands for the project.

The assembly will also be supported by a gantry to limit the movement to only be planer. The gantry being used will be from the lab and will permit vertical and horizontal motion. Along with the robot, it will also hold the power cables to the robot to reduce the amount of additional weight it will add to the system. Minimal weight and force effects will be exerted on the robot by the gantry to make the system consistent. The figure showing the motor locations and generalized coordinates is below.



3.2 Simulation Model

This system will have five generalized coordinates: the horizontal position *x* of the toe, the vertical position *y* of the toe, and the angles at each of the three links q1, q2, and q3. The system will be simulated in MATLAB using the motor locations as virtual torques and with the ground implemented as a virtual contact force. In the model, the robot's foot will be in contact with the ground to start, but the state of the toe will be the focus of the simulation. The robot will also be constrained by a rail to just move in the horizontal and vertical frames. These constraints will simplify both the control law and minimize the number of variables in the experiment. Using the full system simulation, we will be able to vary the stiffness and damping coefficients for each of the three motors. We can then use Matlab to determine a jumping trajectory that optimizes the horizontal distance the robot travels. During the optimization, we will apply constraints to the total simulation time, maximum torques of the motor, and starting orientation.

To be clear, the simulation model and hardware model is an extension of the pset problem where we derive an additional DOF for the pendulum. We expect to use the basis of the deriving and simulating MATLAB code and add an additional degree of freedom, with a simulated motor near the 'knee' joint of the 2DOF leg. We then add an additional 'toe' controlled by a belt that starts from the additional 'knee' motor. We hope to run optimization control, levarging from pset-5, to design the general structure of the simulation. We will aim to optimize horizontal distance travelled with ground constraints, time constraints on the control profile, and joint limit constraints in order to enforce a 'kangaroo - like' motion.

For the experiment, the robot will start from rest on the ground. Here, the ground refers to the endpoint link to be fully located on the ground, flat. Then, the robot will activate all three motors and perform a single, continuous motion jump. The final x position of the robot will be recorded as well as the total energy used throughout the jump. Part of the experiment will explore if any initial forward tipping of the robot allows the motors to generate a larger horizontal force and therefore increase the jump distance. This specific part of the experiment arises from video footage of a kangaroo initiating a jump from a static starting position.

3.2 Control on Hardware

Stating that our controller is optimal, as above over the constraint that it needs to follow a specific objective function, the constraints are what we will be iterating over. Specifically, the starting conditions/ starting configurations. There will be carefulness to establish the starting configurations as close as can be to the simulation, such that the control law is followed. If observed that the control is too different, we can fall back on Operational Space Impedance Control as we have all of the dynamics well modeled through the Operational Space Mass matrix and the Operational Gravity Matrix in order to better model the dynamics we are exposing the leg to. In this case we iterate over the gains as we wish to follow a bezier curve that is arbitrarily set by us, but with the educated guess that it is optimal for length of jump.

Assuming optimal control works well for the constraints we have established, then: Control will be done through mbed and cables will be lengthened such that we can run and quickly iterate on mbed from the computer. We will be subjecting the leg to the same controlled conditions. Changing the angles q1, q2, q3 will be our initial conditions, as well as total control time for the initial guess.

4. Expected Results

In a typical scenario, we will have run the optimal control on a set of initial conditions that act as the initial constraint, as well as constraints on total control time and dynamics constraints to avoid the infinite solution problem. Having tested the horizontal distance from a starting position, we expect to find an optimal starting position that maximizes horizontal distance travelled. We expect that much like a frog, starting off from a very compressed leg would give us the ideal starting condition, since the stored potential energy as tension could be helpful for the robot, and the more operational space the robot can use to output an impulse, the further we may be able to go, as the leg center of mass moves with the impulse. A surprising result would be that the starting configuration is not completely compressed, indicating some low stiffness or enough actuation on only one end motor.

Q2 and Q3 are the generalized coordinates for the knee and ankle, while Q1 is the hip that controls the 'tilt' of the entire leg. We expect that Q2 and Q3 such that the leg is compressed is the furthest distance, but a starting change in Q1 we can only make educated guesses on from watching videos at this point. Q1 controls the 'direction' of the impulse for the jump, so expecting it to be initialized to have a large horizontal component would be the best guess.

5. Project Schedule

5.1 Proposed Timeline

Category	**Task**	**Due Date**	**Person Responsible**
Proposal	Draft	Oct. 30th	Everyone
Proposal	Complete	Oct. 31st	Everyone
Hardware	Finalize Design	Nov. 3rd	Steven + Sandra
Hardware	Final CAD	Nov. 10th	Steven + Sandra
MATLAB	Simulation Model	Nov. 10th	Jose + Rob
MBED Code	Complete	Nov. 17th	Jose + Rob
Hardware	Complete Hardware Assembly	Nov 20th	Steven + Sandra
Hardware	Hardware Testing Done	Nov. 24th	Steven + Sandra
MATLAB	Trajectory Optimization	Nov. 30th	Jose + Rob
Final Presentation	Full System Tests Done	Dec. 1st	Everyone
Final Presentation	Final Poster Done	Dec 3rd (Friday)	Everyone
Final Presentation	Final Presentation	Dec. 8	Everyone