Robotics with MuJoCo, HW 3
Homework due on 02-20-2022, Topics: Finite State Machine in MuJoCo
Email solutions to pranav@uic.edu.
I highly recommend doing this project in a group of 2 students. Each student can model and develop controller for one strategy and analyze the solution together.

1 Overview

There are multiple ways to pump a playground swing. For instance see this video `https://youtu.be/ZxBCYLfgTOY`. Here is a robot from my lab that pumps a swing from the standing position `https://youtu.be/mNHBRSlg1EM`. You will model, simulate, and analyze the pumping of the playground swing from the sitting and standing position using MuJoCo. Here is a paper that describes modeling (optional read): *Wirkus, Stephen, Richard Rand, and Andy Ruina. "How to pump a swing." The College Mathematics Journal 29.4 (1998): 266.*. Your goal is to demonstrate the main conclusion of the paper that one type of pumping is better than the other one (see Sec. 2.3)

2 Two strategies for pumping a swing

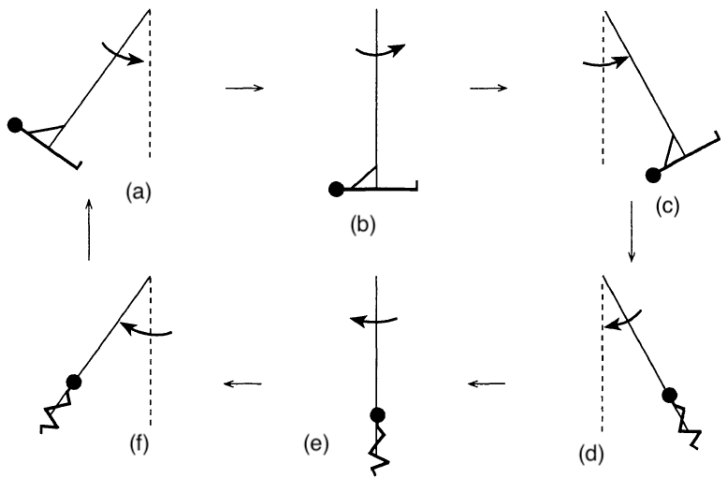

Figure 1: Pumping a swing from the sitting position

2.1 Strategy for pumping a swing in the sitting position

The strategy for pumping the swing is shown in Fig. 1. Here, the amplitude build is due to increase in angular momentum mainly due to the rotation of the body. The motion starts from the left extreme position with the rider in the horizontal position (a). When the rider reaches the extreme right position, she/he uprights the body effectively increasing the angular momentum (c). Thereafter, when the rider reaches the left extreme position, he/she orients the body horizontally again further increasing the angular momentum (f). This completes one swing.

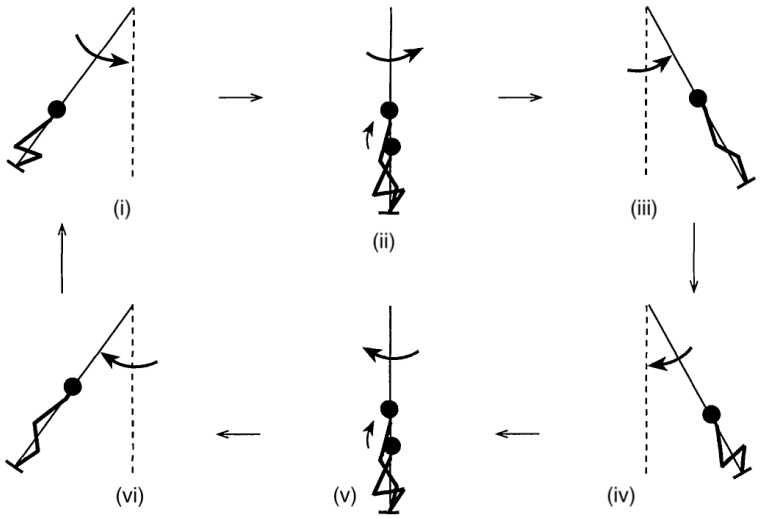

Figure 2: Pumping a swing from the standing position

2.2 Strategy for pumping a swing in the standing position:

The strategy for pumping the swing is shown in Fig. 2. Here, the amplitude build is due to increase in angular momentum due to the change in effective length of the pendulum. The motion starts from the left extreme position with the rider in the squatted position (i). When the rider reaches the mid position, she/he stands up effectively decreases the length of the pendulum (ii). This serves to increase the angular velocity of the pendulum. When the rider reaches the right extreme position, he/she squats again (iii and iv). There after, the rider stands up in the mid position (v) and squatting again in the left extreme position (vi and i) to complete one swing cycle.

2.3 Which strategy is the best?

The motive of pumping the swing is to get to a certain amplitude as fast as possible. The paper's main conclusion is "the seated pumping is better at low amplitudes, but above a certain amplitude the standing pump is more effective" (see end of first page). **Your main goal in this project is to demonstrate this observation using modeling, control simulations, and visual analysis.**

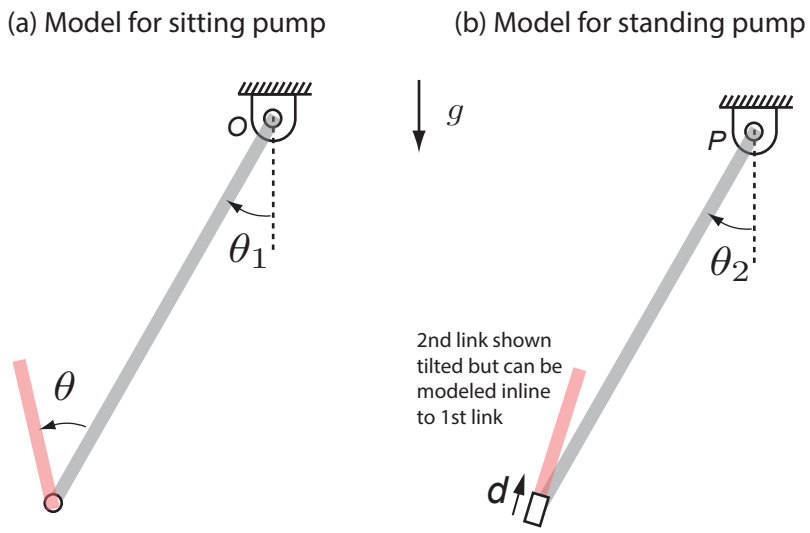

Figure 3: Modeling the sitting and standing pump in MuJoCo

3 Modeling, control, and analyses in MuJoCo

3.1 Model

Figure 3 (a) and (b) shows possible models for the sitting and standing pump. Each model has two links, link 1 is attached to the ground and link 2 attaches to the link 1. Link 1 is described by the angles θ_1 and θ_2 as shown. For sitting pump, there is a hinge joint (θ) and for standing pump, there is a prismatic joint (d) between links 1 and 2 as shown. When modeling, it is important to keep the dimensions, mass, and inertia of the left and right systems the same. I recommend making the link 2 mass substantially higher than link 1 (e.g., 5:1 or 10:1). I also suggest keeping the length of link 1 substantially higher than link 2 (e.g., 4:1 or 5:1). These are just suggestions, feel free to use your own judgement and intuition. Please model these systems side to side in the same file, so it is easier to compare their motion.

3.2 Control

Based on the strategies explained in Sec. 2.3, program the 2nd joint to pump the swing. I recommend starting both the pendulum at the same angle $\theta_1 = \theta_2 \neq 0$. For the sitting pump, you could move the 2nd link by 90° as shown in the Fig. 1. For the standing pump, you need to use your judgement on how much displacement you would allow for the 2nd link. I recommend using a proportional-derivative or proportional-integral-derivative (i.e., position control) for control the 2nd link in either case. Its more important that these position control have the desired visual and pumping effect so you might have to tune the gains and set points accordingly. Slow down the animation speed to visually check if you code produces the intended motion for the 2nd link (e.g., standing up at mid-swing).

3.3 Analyses

The goal of analysis is to understand under what conditions one strategy is better than the other. The first page of the paper gives a nice overview including the main conclusion, but feel free to read the other parts of the paper as needed. I have also summarized the main conclusion in Sec. 2.3. Submit the following. (1) Use either a visualization of the two pendulums side by side saved as a movie file graphs to demonstrate the main conclusion of the paper. 2) Send your folder(s) so I can run the code on my end.