ME 410 Robotics

Project #2, Pumping a playground swing, due via online meeting with the instructor from 10/26 or 10/28 or 10/30 (time is TBD)

For team projects, please ensure all team members are contributing to the project. There could potentially be a written peer review.

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 Coppelia Sim. 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.* (paper is uploaded). 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

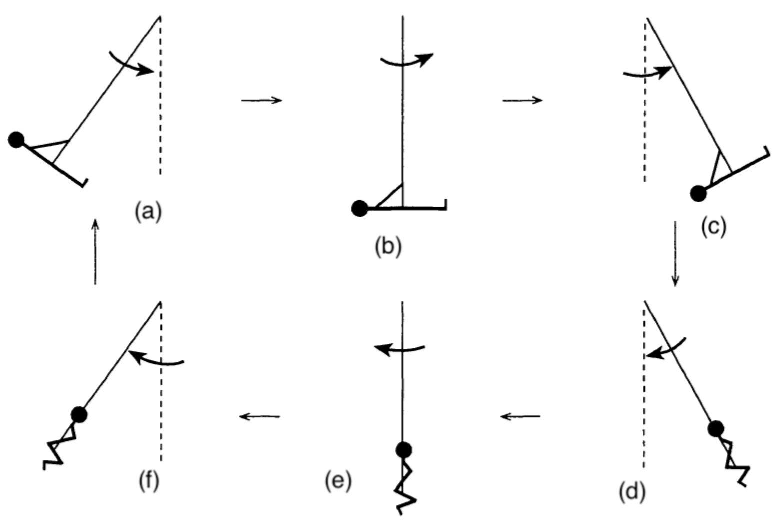

Figure 1: Pumping a swing from the sitting position

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.

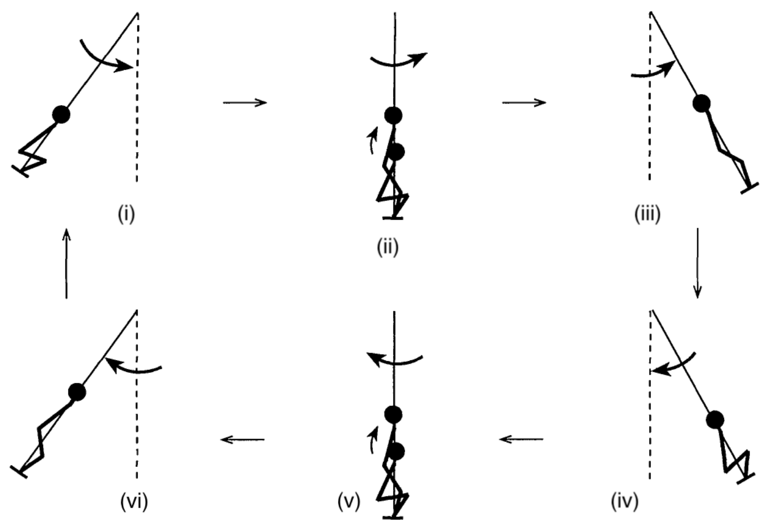

Figure 2: Pumping a swing from the standing position

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.**

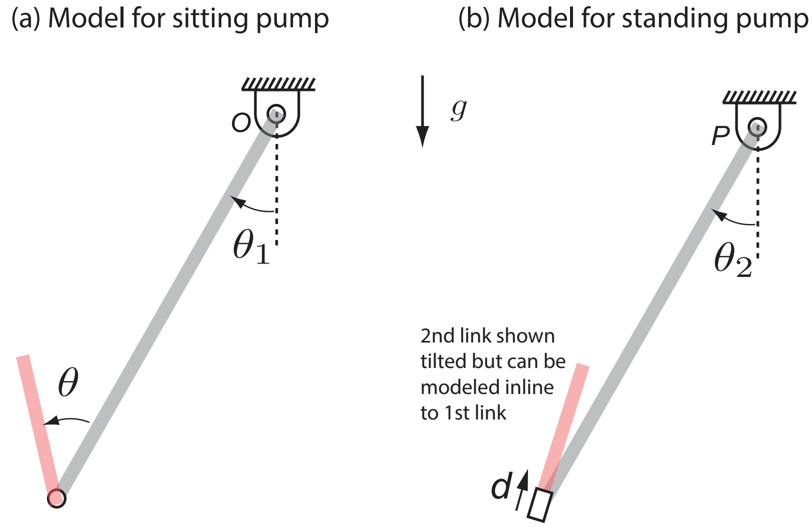

Figure 3: Modeling the sitting and standing pump in Coppelia Sim

3 Modeling, controlling, and analyzing in Coppelia Sim

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 $\theta_1 = \theta_2 \neq 0$. It might be helpful to review HW5, Q4 on event-based control before coding. 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). One way to slow down the animation is to change integration to $dt = 10$ ms and de-select real-time.

3.3 Analyses

The goal of analysis is to understand under what conditions one strategy is better than the other. The first page 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. After you finish analysis, streamline the simulations you will show the instructor while grading. I believe you can present 1 to 2 simulations and animations to demonstrate which strategy is better and when. I am not looking for extensive analysis here. I want you to be able to set up a simulated experiment to analyze a robotics system.

4 Starter file (optional)

Using my starter file and/or using any information from it is optional. I am providing this file as it might make it easier for you to develop the controller and subsequent analysis. The starter file is *pump_swing.ttt* in which I have already modeled the two pendulums. I have put hints in the Lua script to help you get started. It might be best to work on one pendulum at one time.

5 Grading (100 points as given below)

1. Modeling: $15 \times 2 = 30$ points. I will be checking if you have modeled the pendulums correctly. See Sec. 3.1 Already done for you. Everybody gets full points for this part irrespective if you used my starter file or not.

2. Control: $20 \times 2 = 40$ points. I will be checking if both the pumping strategies have been set correctly. Please slow down your animation. One way to do this is to set the integration to $dt = 10$ ms and de-select real-time. See Sec. 3.2.

3. Analyze: 20 points. I will be checking if you can demonstrate which strategy is best and under what conditions using comparative simulations. Please read Sec. 3.3 for expectations. Most importantly, keep it short and simple.

4. The modeling, control, and analysis will be graded by the instructor on 10/26 or 10/28 or 10/30 via a $5 - 10$ min zoom call, just one meeting. Student/Student group of 2 or 3 should be ready to share their screen. Alternately, they may send their code to the instructor and talk to the instructor via zoom. Instructions will be provided later on how to set up meeting with the instructor. Ensure that all team members contribute to the project.

5. Email submission: 10 points. The finalized CoppeliaSim <filename>.ttt file should have the names of all students in the <filename> and also put author names as a comment inside the Lua script preferably in the beginning. The .ttt file should be submitted no later than 10/30 via email to pranav@uic.edu.