Le Grand Pendulum Project

PHYS-311: Classical Mechanics, Spring 2018

Project logistics:

- The project is be done in teams of one or two people (but no more than two).
- Project Deadline: 2018, April 20.
- Submission criteria: Email me a link to a web report/paper you/your team created that includes sections on (at least, but not limited to)
  - Goals of the Project
  - Description of the Experimental Apparatus
  - Data Collection Procedure
  - Data Analysis Procedure
  - Discussion and Conclusions
  - Bibliography
  - Appendix containing the code(s) you wrote for this project.
- The final report should contain an ample number of plots, figures, and tables to defend your work. Sections should have section headings. All images, figures, tables, etc. should have appropriate captions. Feel free to include links to external resources. Give credit to information gleamed elsewhere (as my undergrad mentor Prof. Debapriyo Syam used to say – *acknowledge, and be acknowledged*).
- Bring out the scientist in you. Follow the scientific method, and be a stickler for accuracy and detail. Remember that, in the words of Thomas Edison, "Genius is one percent inspiration and ninety-nine percent perspiration." (But for the sake of your teammate, do wear deodorant!)
- Be pedantic. Don't take any quick-and-dirty shortcuts. Justify every step.
- This project is worth 10% of the final grade. That is, about 2/3 the mid-term exam grade, and 1/2 of the final grade! But unlike the exams I am there to guide you/your team if/when you are stuck.

1. Project goal

If the damping force F_d in a real-life pendulum experiment with moderately large amplitude is $F_d = -bmv^n$, where m is the mass of the pendulum's bob, v its velocity, and n a real number (probably n is close to one), then our goal is to determine the values of b and n by finding the numerical model that best fits experimental data.

2. Getting data

We have set up a pendulum in the experimental physics room. We will go there, and carefully (i.e. without disturbing other ongoing, potentially Nobel-prize-worthy, experiments) take videos of the pendulum in motion with our cellphones. Some helpful hints:

- Ensure adequate lighting.
- Keep the camera at least 2–3 meters away from the pendulum. Then distortions introduced by the lens are small.
- One teammate operates the video while the other gets the pendulum moving.
- Start your video a few seconds after your partner gets the pendulum going. Stop video a few seconds after the pendulum is not moving. You will need the last part for determining the equilibrium position.

3. Extracting data from the video:

- You can first upload your video on google drive, and then download the video on one of our (Physics & Astronomy Department's) laptops.
- You can then "Insert" this movie into your favorite software *Logger Pro*[1]! Unfortunately *Logger Pro* is an expensive software and only installed on the laptops.
- In *Logger Pro* you can look at the video frame-by-frame (or every N-th frame) and click on the center of the pendulum to record its X and Y pixel position as a function of time.
- Since most cell phone cameras will record about 30 frames per second (or more), even a small 3-minute long video will contain thousands of frames. Since our laptops are oooold (sorry!), it will take quite a while for *Logger Pro* to load your video. Please be patient.
- Since the pendulum's motion is not that fast, you can ask *Logger Pro* to advance by a certain number of frames so that you are looking at frames that are separated by, say, 1/5-th or 1/6-th of a second. Look under *Options* ⇒ *Movie Options*. That reduces the number of frames you have to click by a lot, but still maintaining good quality data. (Of course I wouldn't stop you if you wanted to go through every single frame!)

[1] OK, maybe it is not your favorite software ... not mine either, but it works ... unless of course you want to write your own pattern recognition code [which is actually not that hard, but maybe we leave that as a summer project])

- Once you have extracted all the useful data from the video, you should export the data as a CSV file (comma separated variable) by going through *File* $\Rightarrow$ *Export as* $\Rightarrow$ *CSV*. This will create a simple text file where each line has the following format:
  time, x, y, x velocity, y velocity.
  We will need only the first three quantities: time, x, and y.

- Then we need to read this data in the CSV file into python for further analysis. I have attached a code snippet below that reads different columns of a CSV file into different arrays (lists).

- Once you have read the time and positions in python then you can calculate the angle $\theta(t)$ that the pendulum makes as a function of time.

```
# Read the data in pendulum_data.csv
# and do some plotting.

import numpy as np
import matplotlib.pyplot as plt

# ip is the name of the file we read.
# The first line of this file is the header (metadata)
# The actual data starts from the second line
ip='pendulum_data.csv'

# Time is the 0-th column, X is the 1st column, Y is the 2nd column
tt = np.genfromtxt(ip, usecols=(0), delimiter=',', skip_header=1)
xx = np.genfromtxt(ip, usecols=(1), delimiter=',', skip_header=1)
yy = np.genfromtxt(ip, usecols=(2), delimiter=',', skip_header=1)

plt.plot(xx,yy,'r-')
plt.xlabel('Time (s)')
plt.ylabel('X (pixels)')
plt.show()
```

4. Modeling the data

We assume a pendulum with non-small amplitude. Then the equation of motion, as we discussed in class, is:

$$\ddot{\theta} = -\omega_0^2 \sin\theta \tag{1}$$

where $\omega_0^2 = \sqrt{g/l}$. In real life there is also damping. The damping force is often taken to be linearly proportional to the velocity, but in general the damping may be non-linear in velocity. In general we can write the damping force as $F_d = -bmv^n$, where b is the *damping parameter* and n is the *damping exponent*. We expect n to be a real number close to one but not necessarily equal to one. Since the velocity v of the pendulum's bob is related to its angular velocity $\dot{\theta}$ as $v = l\dot{\theta}$, the equation of motion after including damping becomes

$$\ddot{\theta} + bl^n\dot{\theta}^n + \omega_0^2 \sin\theta = 0 \tag{2}$$

Our modeling goals are therefore:

4.1: Determine the length l of the pendulum and ω_0^2 by measuring the period when the amplitudes are small (you can use the end of the video for this). To find an exact value of g, do a Google search on 'wolfram widget local acceleration of gravity' and use the Wolfram Alpha widget for Norton.

4.2: Write a numerical code that will give you $\theta(t)$ once you specify b, n, l, and ω_0^2 (these are called the model parameters), and the initial conditions (i.e. values of $\theta(t = 0)$ and $\dot{\theta}(t = 0)$).

4.3: Tweak the values of the model parameters b and n until your model matches *well* with the data.

- What quantitatively is a "best fit" model for your data? We'll talk about it after the break.
- **Try writing the code for equation (2) during the break.**