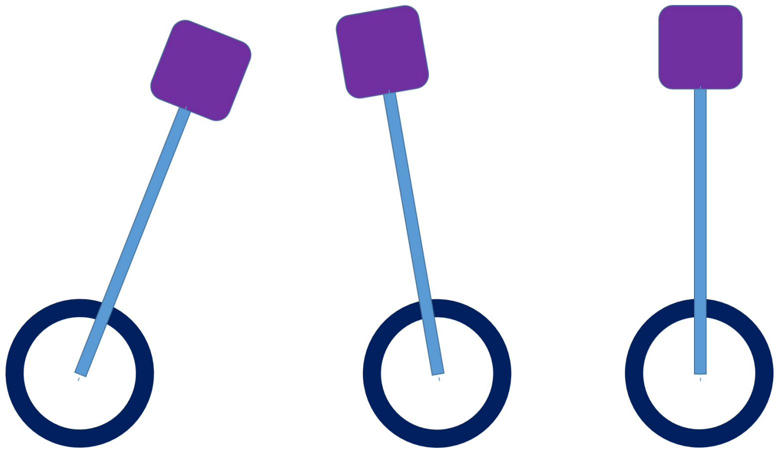

Introduction

In this last part of Engineering Systems Analysis, you will apply many of the approaches you have learned thus far in a classic problem in control theory - balancing an inverted pendulum. This problem often shows up in both Dynamics and Signals and Systems classes. This problem also shows up in real life, e.g. the Segway scooter, and various robotics applications. If you are interested to see a classic discussion and demonstration of this problem, please visit this link: MIT OCW Signals and Systems Lecture 26. Note that this video is completely optional. [1]

You are going to balance inverted pendulums yourselves. You will be using the Pololu Balboa robot platform with an extension designed by Olin student Hannah Kolano, and alums Eric Miller and Claire Kincaid. The combined setup has been cleverly named "Rocky" by our very own Paul Ruvolo. Instead of using the heuristic method of balancing the robot provided by Pololu, you will be using the analytical tools you have learned to get the robot to balance.

However, given that this is the real world, it is very likely that your robot will not behave exactly as predicted by analysis. So some hand tweaking of the system is inevitable.

Our hope that by the end of this project, you will have the experience of using analytical and numerical techniques, combined with experimentation to solve a classic problem in controls, and have some fun doing it.

[1] They use a slightly different approach to controlling the inverted pendulum as they have a system where the acceleration can be controlled easily.

The challenge

Your goal is to get your robot to balance and do something interesting. “Do something interesting” could be one or more of the following

- Balance in a square for as long as possible
- Dance around the floor to music
- Go up a ramp
- Follow a track on the ground
- Any other interesting thing

The deliverables

You will need to submit a report by Mar 13 which minimally contains the following

1. A description of your system implementation.
2. What challenge(s) you attempted.
3. A block diagram of your control system.
4. The poles of your designed system, and a description of why you chose them.
5. A link to a video of your robot standing up.
6. Any code that you wrote.
7. Your system should

A demonstration of your system in class on Mar. 13.

Getting started

General Instructions

- Please be gentle with Rocky
- Please only run Rocky **on the floor** and not the table.
- Please keep in mind that we made Rocky longer so it would better match analysis, knowing that it will be more fragile. So please try to **catch it before it falls.**

Setup, calibration and balancing

1. Follow the instructions on setting up tools for Rocky on the Canvas site.
2. Read the document "Controlling an Inverted Pendulum on a Cart" linked on the canvas site.
   - This document is long. It starts with deriving equations of motion for the inverted pendulum, and ends with a block diagram of the system to control the pendulum. Take your time with it.
   - Note that the approach in this document is a little bit different from the homework problem on the pendulum control.
   - The approach written up in this document is implemented in the starter code, but without the control parameters.
3. Assemble Rocky
   - Get a robot platform, USB cable, 6AA batteries, 2 screws, 2 nuts and 20 washers from the front of the room.
   - Using the screws and nuts, attach 10 washers to the left and 10 to the right on top of the Rocky frame (the MDF part). These will help move the center of mass of the Rocky frame closer to the top.
   - Attach the bottom of the Rocky frame to the Pololu platform.
4. Calibrate the Gyro. Use the Rocky_Gyro_Calibration sketch to calibrate Rocky. Instructions are available in the comments on top of the main file.
5. Find the natural frequency and the effective length of Rocky using the Rocky_Gyro_Calibration sketch. Note that the model of a massless rod with a mass at the end of it is idealized. So we need to find the effective length of the pendulum here. Again follow instructions in the comments.
6. Use the Rocky_Balance_Starter_Code sketch to get started with your balancing algorithm. Follow the instructions in the comments in the code.

Some Specifications on Rocky

- The Rocky is approximately 22 inches tall from weight to axle. But the effective length is shorter.
- The motor model we recommend has a transfer function $\frac{ab}{s+a}$. The values of a and b vary depending on robot. we have found that $a = 14$, $b = \frac{1}{400}$ are good numbers to start with, but to further optimize your system, you will need to characterize the motors.