The presentation for the final project should be approximately 20-25 minutes with an additional 10 minutes for questions. Each member should present on some aspect of the project and be prepared to answer questions after the presentation. Members of each group will turn in a “grade” for each of the other members in the group at the presentation to evaluate how much each member contributed to the project. You may split up tasks however you wish, but each member of the group must understand the project as a whole! You are to submit your slides as handouts on Canvas prior to your presentation. One slide should show your Matlab code where you simulate the control system.

The final project requires you model the provided systems, develop a controller to control the system, and provide a control m-file that will be used to evaluate the controller. The form of the function will be provided (i.e. inputs, outputs, and function name) to streamline the evaluation process. Note that each team will only be allowed 2 evaluation chances and the evaluation serves as 50% of the final project grade (the other 50% is the presentation).

You may submit your control m-file at the following scheduled times via canvas. Teaching Assistants will test the system and provide an evaluation with 48 hours.

- Monday, April 20, 5 pm
- Wednesday: April 22, 5 pm
- Wednesday, April 29, 5 pm

The final project is broken into several steps below to highlight various aspects of control theory. The system models are complicated. Do not wait until the last minute. You should provide your equations of motion, the closed-loop eigenvalues that you designed, and the expected step response performance (t_s, t_p, etc.) each time you submit your controller function. These values should have been verify in your own simulation prior to submitting a controller function for evaluation. This may help the TAs to give you meaningful feedback should your controller fail the evaluation.

1. **System Model:** Develop the model for your system (EOMs). Your team should develop a Matlab function (or Simulink block) that takes in the system input and provides the specified outputs. Your simulation should account for any real limitations such as actuator saturation.
   a. Simulate your open loop system (step responses)
   b. Sketch the roots of the system (poles and zeros)
   c. Sketch the Bode Diagram of the system

2. **Controller Design:** Develop a Matlab function that takes in the specified system outputs and commanded reference and generates the control input to the system.
   a. What type of controller was used?
   b. Where are the closed loop roots?
   c. What is the closed-loop bandwidth? DC Gain?
   d. What is the step response of the closed-loop system?
   e. Test the tracking ability of your controller. Does it correlate with the bandwidth of your closed loop system?
3. **Controller Test (Evaluation):** You must submit your Matlab control function which will then evaluated by checking
   a. How well does the system track different references?
   b. How does it react to various disturbances?
   c. Is the controller robust to variation in parameters?
   d. Does the controller handle sensor noise?

4. **Sensor Considerations:** Select sensors to provide the measurements that you used to observe the state of your system (i.e. the measurements you used in your Matlab function or Simulink block). You must select REAL sensors.
   a. Model the dynamics of your sensor if necessary
   b. Do your sensors have any dynamics/constraints that must be considered?
   c. Simulate your system open loop (i.e actuator->system->sensor)

**Notes/Comments on the Final Project**

1. Make sure you have one slide showing your Matlab plant and controller functions (that shows where you calculate error and your control input and the simulation of your system).

2. Make sure you don’t cheat in your simulation in terms of what measurements or inputs you have. For example, if you only have a sensor that measures error, you must derive the derivative of error from your error sensor (or show that you have a second sensor). You cannot just take velocity from your simulation.

3. You are free to divide up tasks but realize that you will be tested on the Final Exam on modeling, analysis, and controls (not on sensors and actuators or presentation development). So, if your task is not relevant to the specifics of MECH3140 it may have costs on the exam.

4. Submit your sensor specification sheets along with your presentation.
MECH 3140 Final Project
Presentation Uploaded to Canvas: April 22, 11:59 pm
Project Presentations April 23-24

Inverted Pendulum on Cart

Derive the system model for the inverted pendulum on a cart. Assume that the person can be modeled as a point mass at length \( l = \text{height}/2 \) from the base. Nominal values for \( l \) and the mass of the rider are given. The rider’s inertia can be derived by assuming the person is a slender rod. The mass of the Segway base in the table includes the mass of the wheel. Assume the center of gravity the base is at the center of wheel, and that the pendulum is on a free pivot attached to the base (i.e., the motor torque does not react against the pendulum). Assume no slip between the ground and the wheel(s) of the cart.

Design a control system with the follow information:

Measurements: Cart position \((x)\), pendulum angle \((\theta)\),
References: pendulum angle \((\theta)\),
Controllable Variables: Voltage to motor

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Name</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( m )</td>
<td>Mass of Rider</td>
<td>kg</td>
<td>75</td>
</tr>
<tr>
<td>( l )</td>
<td>Height of CG of rider</td>
<td>m</td>
<td>1</td>
</tr>
<tr>
<td>( M )</td>
<td>Mass of Segway Base</td>
<td>kg</td>
<td>47</td>
</tr>
<tr>
<td>( R )</td>
<td>Wheel Radius</td>
<td>cm</td>
<td>29</td>
</tr>
<tr>
<td>( J_w )</td>
<td>Inertia of Wheel</td>
<td>Nm/rad/s²</td>
<td>0.085</td>
</tr>
<tr>
<td>( L )</td>
<td>Motor Inductance</td>
<td>Henry</td>
<td>0.82x10⁻⁶</td>
</tr>
<tr>
<td>( R )</td>
<td>Motor Resistance</td>
<td>Ohms</td>
<td>1.03</td>
</tr>
<tr>
<td>( J_m )</td>
<td>Inertia of Motor</td>
<td>Nm/rad/s²</td>
<td>6.7x10⁻³</td>
</tr>
<tr>
<td>( K_v )</td>
<td>Motor Voltage Constant</td>
<td>V/rad/s</td>
<td>2.25</td>
</tr>
<tr>
<td>( K_t )</td>
<td>Motor Torque Constant</td>
<td>Nm/A</td>
<td>2.25</td>
</tr>
<tr>
<td>( b )</td>
<td>Motor Torsional Damping</td>
<td>Nm/rad/s</td>
<td>5.0</td>
</tr>
</tbody>
</table>