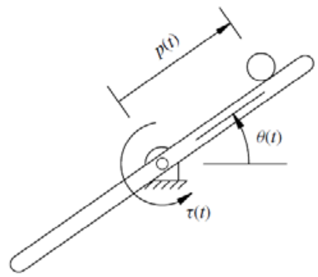
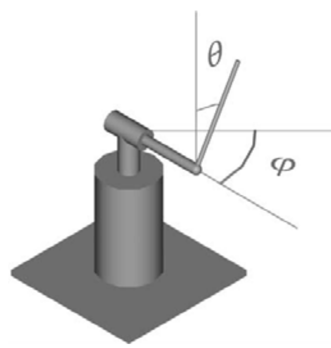
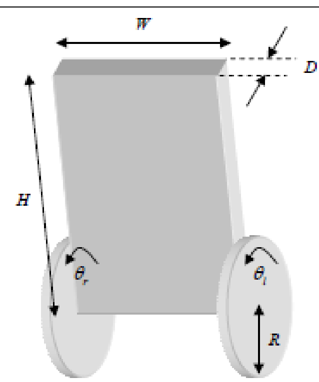
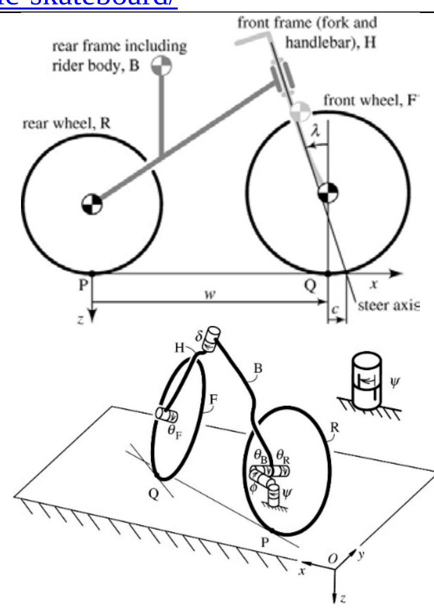
School of Mechatronic Systems Engineering
MSE 483/782: Modern Control Systems/Introduction to State Space Control Systems

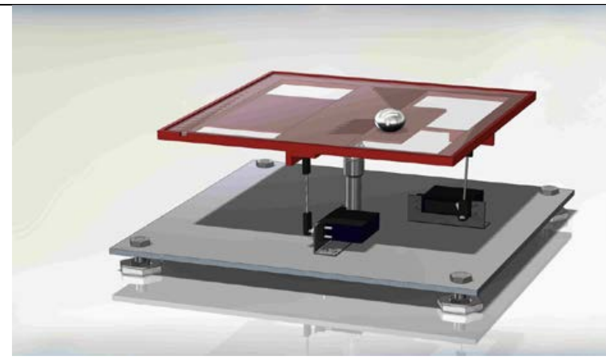
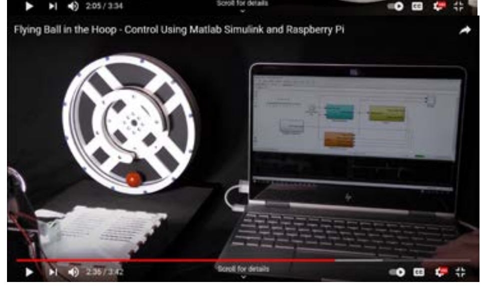
Course Project

The students will design a feedback control system using state-space methods covered in the course. Undergraduate students can from groups of 3 (maximum) to work on each project. Graduate students will perform their projects individually. Some project ideas **are listed in the table below** (figures are taken from corresponding references)**.** Further technical details of the proposed systems can be obtained by referring to suggested/other references. The students should select reasonable numerical values for the parameters required to perform design and simulation/experimental studies.

Control of a rolling ball on a slotted beam: This project involves stabilization of a rolling ball on a beam actuated by a DC motor. See Chapter 1 of textbook by Robert L. Williams, II, Douglas A. Lawrence, "Linear State-Space Control Systems," *J. Wiley & Sons*, 2007. **NOTE: THIS PROJECT WILL BE DISCUSSED IN THE COURSE AND WILL NOT BE ALLOWED (unless done experimentally)**	
b) Stabilization control of an inverted pendulum on a rotating platform. See, for example, the following article for dynamic modeling of the system: I. Fantoni and R. Lozano, "Stabilization of the Furuta pendulum around its homoclinic orbit, *International Journal of Control*, Vol. 75, No. 6, pp. 390-398, 2002.	
c) Control of a two-wheel self balancing robot (Segway human transportation device). See, for example, the following link: http://www.pages.drexel.edu/~dml46/Tutorials/BalancingBot/files/NXTway-GS%20Model-Based_Design.pdf	

d) One wheel scooter/skateboard https://royalsocietypublishing.org/doi/10.1098/rsif.2016.0345 https://www.scirp.org/journal/paperinformation.aspx?paperid=1661	https://onewheel.com/products/pint:  https://www.coastoutdoors.ca/product/onewheel-pint/ https://www.youtube.com/watch?v=pexIvybyZ5U https://partsolutions.com/engineering-ultimate-onewheel-electric-skateboard/
f) Bicycle dynamics: Analysis and control (e.g., self-riding bicycles; self-stabilizing mechatronic bikes) See dynamic equations https://royalsocietypublishing.org/doi/pdf/10.1098/rspa.2007.1857 See these videos: http://www.mindstormsrobots.com/lego-mindstorms/nxt-based-bicycle-robot/ https://www.youtube.com/watch?v=2YtpPu-SI5M	

Course Project

g) Ball on a plate position control system https://www.youtube.com/watch?v=Rr90hb_Rn3M https://www.youtube.com/watch?v=j4OmVLc_oDw (Sensor: Resistive touch panel mounted on the platform) Papers: http://folk.ntnu.no/skoge/prost/proceedings/process-control-slovakia-2017/data/papers/027.pdf http://www.cis.upenn.edu/~danielkh/files/2011_LinearControl/16.pdf http://lup.lub.lu.se/luur/download?func=downloadFile&recordOId=8847458&fileOId=8859300 http://www.scitepress.org/Papers/2017/64259/64259.pdf	 https://www.google.com/search?q=ball+on+a+plate&rlz=1C1CHBF_enCA747CA747&tbm=isch&source=iu&ictx=1&fir=PKaRioSJSRNhtM%253A%252CdKUYpBxvaEoZJM%252C_&usg=AI4_-kSXo7taht7PxV9T6I7OnHHoRthX6g&sa=X&ved=2ahUKEwjpr57I1bvfAhWIrlQKHe5tBN4Q9QEwCnoECAQQBA#imgrc=PKaRioSJSRNhtM
h) Ball in hoop (flying ball in double hoop): https://arxiv.org/pdf/1706.07333.pdf https://ww2.mathworks.cn/matlabcentral/fileexchange/65356-aa4cc-flying-ball-in-hoop	 https://www.youtube.com/watch?v=8FaNk6C2ckM (see video at minute 2:21) https://aa4cc.github.io/flying-ball-in-hoop/
h) Other projects: If you have other project ideas, please discuss them with the instructor	

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Course Project

THE FOLLOWING DESCRIBES OBJECTIVES AND DELIVERABLES OF THE COURSE PROJECT

1. Objectives

Apply material and concepts discussed in the course in the control design process. In particular the following concepts should be utilized in the design:

a. State-space formulation
b. Analysis of controllability and observability of the system
c. Utilization of state feedback control and state observers
d. Application of optimal control concepts (time permitting)
e. Conduct simulations/experiments and analyze and interpret data to improve the design
f. Apply design and test procedures using computer analysis, design, and simulation tools

Each group is required to come up with a set of requirements based on the system they choose. Students are encouraged to come up with their own ideas in terms of what they want to incorporate into the design and how to simulate performance.

Use of simulation and visualization tools such as SimScape and Matlab animation are highly encouraged. For instance, see the following link for more details on Simscape Multibody: http://www.mathworks.com/products/simmechanics/. Simscape Multibody provides a multibody simulation environment for 3D mechanical systems, such as robots, vehicle suspensions, construction equipment, and aircraft landing gear. The software formulates and solves the equations of motion for the complete mechanical system.

Please note that certain details about using animation tools have to be done by students and TA/instructor may not be able to help.

2. Deliverables

- Working simulation or experimental system that fulfills the objectives listed above. There will be a demonstration at the end of semester for this purpose.
- *Control System Design Report* containing the following sections:
  - Introduction
  - Detailed analysis and design of the system involved. In particular, material discussed in the course should be used and incorporated in the design.
  - Test procedure and simulation results
  - Simulation (or experimental) results specifying the performance of the system designed, how it meets the design requirements, any problems encountered and how they were addressed or would be addressed if you had more time
  - Conclusions
  - Code and simulation files as an attachment
- The report should be prepared in electronic format and submitted via canvas.sfu.ca before the deadline.

<u>NOTE: All students in a group will get the same mark unless the percentage of contribution is listed on the first page of the report.</u>

3. Project Grading:

The following grading rubric will be used (graded out of a total of 100%) to mark the project

Final Report	40%
Operational Simulink and related animation/visualization files	20%
Final Project Demonstration	20%
Lab Activity: Completion of tasks, attendance, and presentation during online lab checkpoints	10%

Final Report Specifications and Grading Criteria:

Title Page Must Include Student Names, Student Numbers, etc.

• Introduction and Description of System (Problem statement)
• Description of Analysis and Design Objectives

a. ***State-space formulation***

b. ***Linearization***

c. ***Open-loop Stability Analysis***

d. ***Analysis of controllability and observability of the system***

e. ***Design and utilization of state feedback control***

f. ***Design of state observers***

g. ***Utilization of state feedback control with the designed observers and comparison of results***

h. ***Application of optimal control concepts (tentative)***

• Simulation results and discussion for all the above Objectives
• Results and Conclusions