LAB 6-MEC830
System Simulation
(Individual Lab)

1. Purpose

The purpose of this lab is to get hands-on experience with system simulation.

2. Scope

You will learn about different components needed to simulate a system. These components include controller, amplifier, etc.. The simulation is done using MATLAB. You will build, simulate, and control an inverted pendulum, as shown below in Figure 1. The system is naturally unstable at $\theta = 0$ and sensitive to small disturbances.

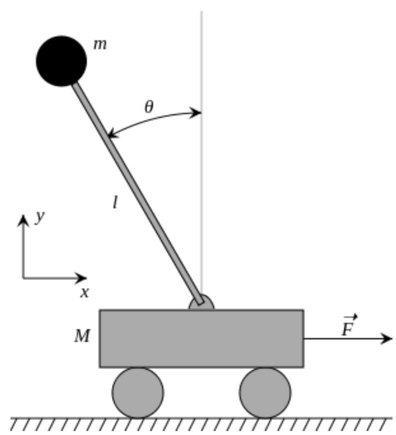

Figure 1: Inverted pendulum[1]

3. Documents

The following documents will help you through the lab:

- Lecture notes

Note: you will need the following toolboxes for MATLAB:

- Simscape
- Simscape Multibody
- Control System Toolbox
- Simulink Control Design
- Signal Processing Toolbox
- DSP System Toolbox

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[1] https://en.wikipedia.org/wiki/Inverted_pendulum

4. Procedure

4-1) Launch `MATLAB`, type `smnew` in the command window and hit `Enter`. `Simulink` with default blocks will start.

4-2) Save the current simulation as an `xls` file.

4-3) Double click on the `Mechanism Configuration` box and verify that the acceleration of gravity on the `z` term is `-9.80665`, See Figure 1.

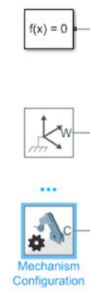

Figure 1: Mechanism Configuration

4-4) **Modelling Cart**

a) Connect the world frame node to the base node of the first `Rigid Transformation` (Figure 2). To create a connection, click a port, terminator, or line segment, and then click a compatible, highlighted model element. The first transformation should be a 90 degree rotation in the +Y axis.

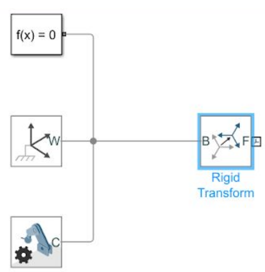

Figure 2: Connecting world frame node to base node

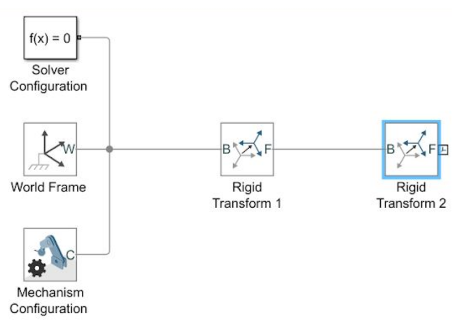

Figure 3: Adding the second transformation

c) Add another transformation. The second transformation should be a 180 degree rotation about the +Z axis (Figure 3).

d) Use the `Library Browser` to search for the `Prismatic Joint` box which will be used for the cart model (i.e. Translational motion with respect to the x-axis).

e) In the `Internal Mechanics` setting, set the `damping coefficient` to `0.1 N/m/s`. For the `Sensing` settings be sure to check `Position` so that the output position of the cart is monitored. Lastly, for Under the `Actuation` tab choose the `Provided by input` option for force. You should apply these settings and a block should be generated as in Figure 4. Connect the B port to the last transformation created.

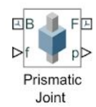

Figure 4: Prismatic joint block.

f) In the `Library Browser`, search for `In1` and `Out1` input and output ports as well as a `PS-Simulink Converter` and a `Simulink-PS Converter.` These are needed to make connections from the prismatic joint block to the outputs and from the inputs to the prismatic joint block. Once the connections are made, double click the converters and set the units to their corresponding inputs and outputs. Also label your inputs and outputs so the graphs produced in the later stages of this lab are comprehensible (Figure 5).

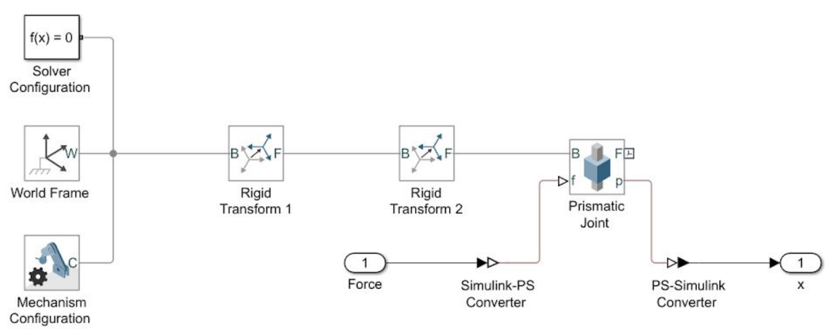

Figure 5: adding converters

h) To complete the cart, connect the follower node of the prismatic joint to the reference node of a `brick solid` with dimensions `0.30m x 0.30m x 1m` and a point mass of `2kg`.

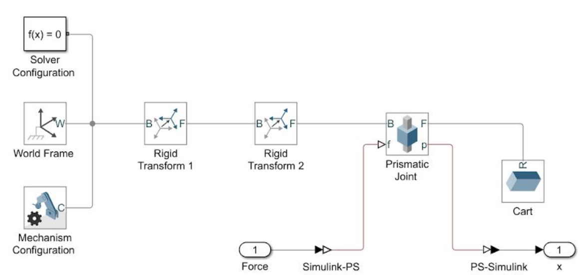

Figure 6: modelling cart

4-5) **Modelling Pendulum**

a) Add a `Revolute Joint` block, and make the connections according to the figure. Under `State Targets` check the `Specify Position Target` option. Under `Sensing` check the `Position` attribute.

b) Add a `brick solid` block to model the pendulum. The dimension of the pendulum should be set to `2m x 0.15m x 0.15`. The point mass of the pendulum should be set to `1kg`. Under the `Frames` tab of the pendulum click the + icon to add a new frame and select the `origin based on a geometric feature`, so that the pendulum is in an initial upright configuration. Rotate the view, click the back surface of the `0.15m x 0.15m` face, then click `Use Selected Feature` to have `Centroid of -x surface`, shown in the textbox below. Refer to Figure 7.

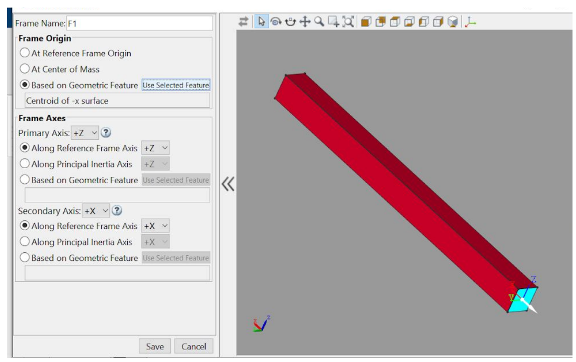

Figure 7:New frame setting for pendulum

Note: You can modify the colours of the cart or pendulum by double clicking on either of their solid brick models then Graphic > Visual Properties and change the `Colour` vector.

d) The third `Rigid Transformation` should be a standard axis rotation of 90 degrees about the +X axis. See Figure 7.

e) Set the `Output signal unit` of the `PS-Simulink Converter` to radians and connect the wire to an output node labelled theta.

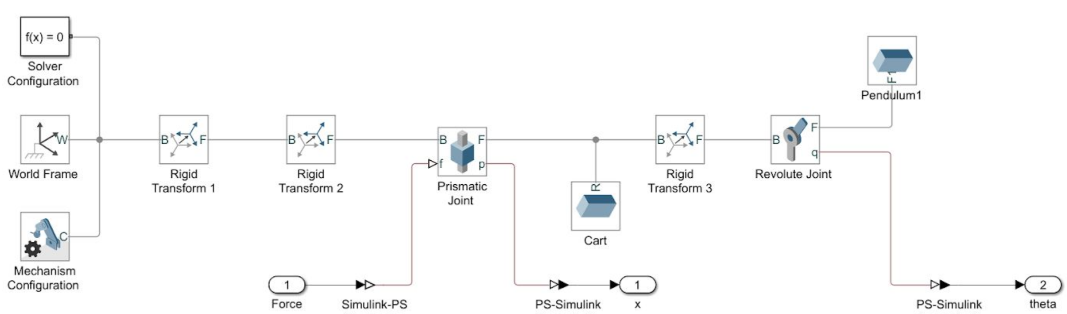

Figure 7: Pendulum block connections with revolute joint and third rigid transformation.

4-6) To simplify the inverted pendulum and cart physical system into a single block press Ctrl+A, then press Ctrl+G. The result should look like Figure 8.

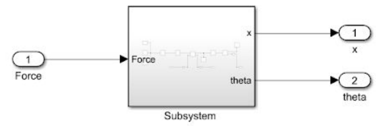

Figure 8: Subsystem block

g) Next we will add a discrete impulse as an external disturbance force. Search for `Discrete Impulse` in the Library and connect it to a gain. Replace the force input with the impulse system (Figure 9). In the next section, you will adjust the gain to disturb θ by ~0.11 radians (~6.3 degrees). At this stage, you can simulate the system and see if the visualization looks right. The system is unstable as there is no control (Figure 9).

Note: The DSP toolkit is required to add the discrete impulse block.

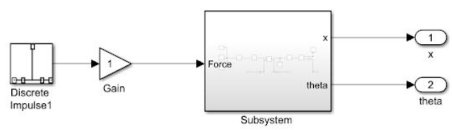

Figure 9:Discrete impulse connection to the system.

4-7) **(Controller)** We will design a PID controller to maintain the pendulum angle at 0 radians with respect to the +Z axis given that the pendulum is initially in an upright position and applied an impulse force at time t=2 seconds to move the pendulum to +0.11 radians. The force required to push the cart to stabilize the pendulum should be computed during the simulation. Follow the next steps.

Figure 10: Initial position

Figure 11: After impulse is applied

4-8) Select the `PID` block, and the `Subtract block`. Connect the theta output variable to the negative node of the subtraction block and connect the constant goal of 0 radians to the positive side of the PID block. The output of the subtraction block should connect to the input of the PID block, and the output of the PID block should be wired to the input of the Force node on the simplified subsystem block (See Figure 12).

4-9) Add `Scope` blocks to monitor the linear position of the cart, the angular position of the pendulum, and the external force applied to the cart to maintain the angular position goal.

4-10) Set the stop time to 10 seconds. Hit the `run` button to begin the simulation. Adjust the PID gain so that the system is stable. Report the PID gain values, Settling time, Percent Overshoot, X vs Time, Theta vs Time, and Force vs Time plots.

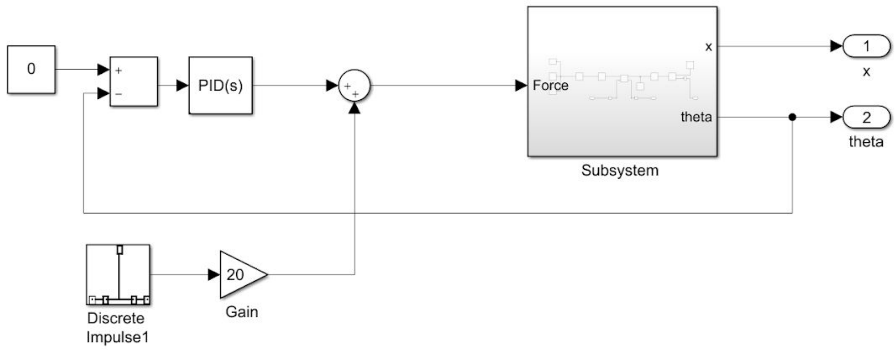

Figure 12: Final system (with one impulse signal)

4-11) Once the system works with one impulse, add a second impulse at time t=6 seconds (apply force again) to destabilize the pendulum in the other direction for about -0.25 radians. The system should react immediately

Watch the videos to see how this lab should work, and what you need to present.
https://youtu.be/qxgfrrS49sM
Once the task is working properly, demonstrate to your TAs and ask them to sign off.

Figures 13-17 demonstrate graphs of impulse, position of the cart, angle of the pendulum, and the control signal over time. Your report should contain similar graphs, with your gains.

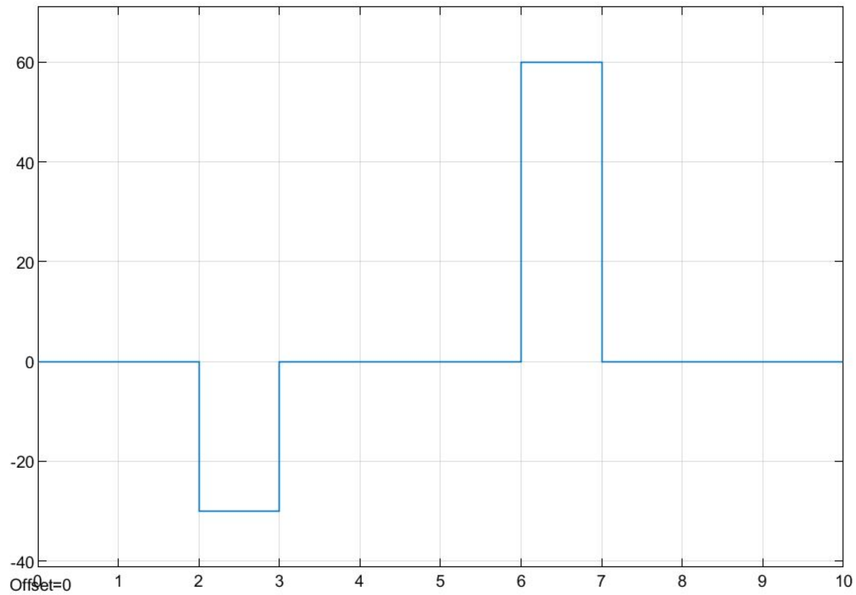

Figure 13: Impulse sequences - force (N) vs time (s)

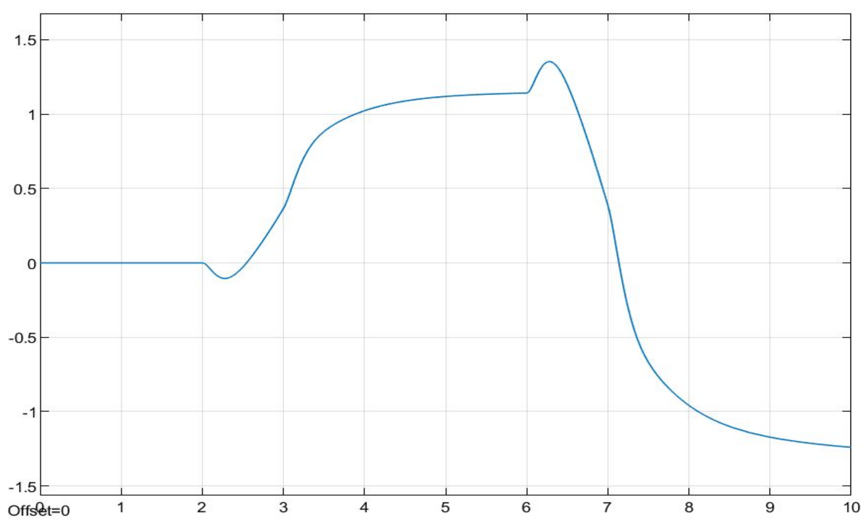

Figure 14: x-position (m) vs time (t)

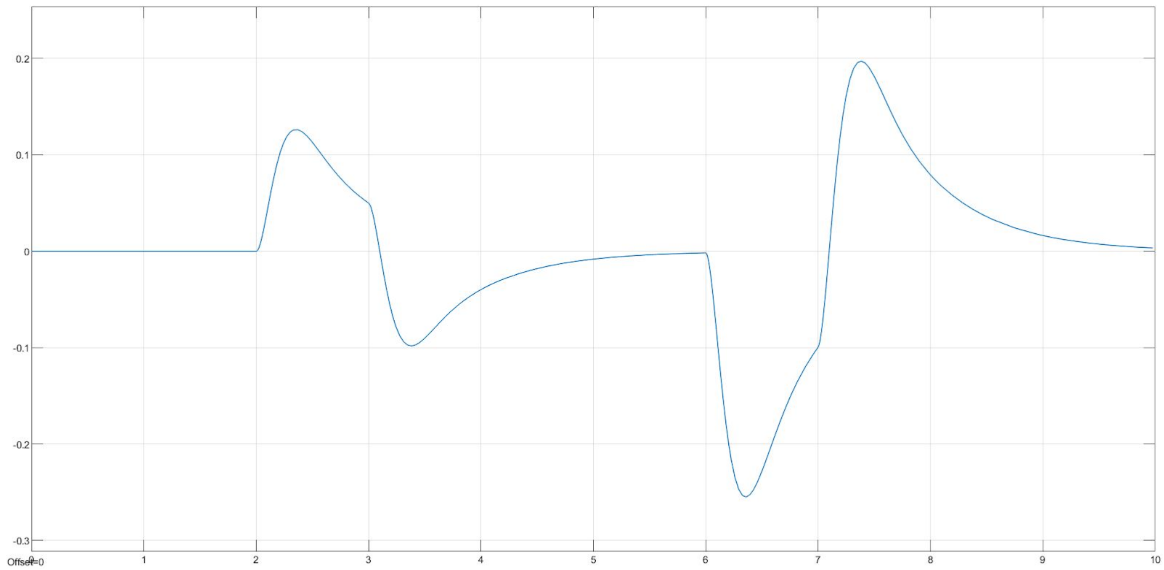

Figure 15: Pendulum angle (rad) vs time (s)

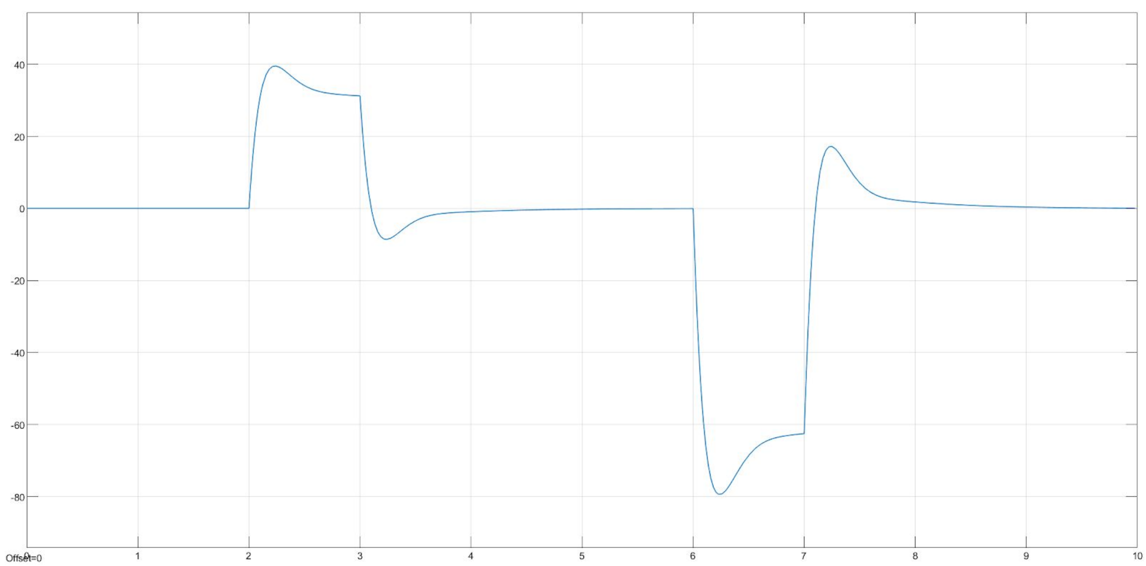

Figure 16: Control signal generated by PID

5. Report

Your lab report should include:

- Signed lab report cover page: http://www.ryerson.ca/mie/documents/
  (make sure you put your lab group number on the front)
- Abstract
- Introduction
- Experimental Tools (ie. what was used)
- Description of the Program with Flowchart.
- Question 1: Make a different disturbance signal of your own choice and report the last four graphs for your signal. Try to find out how far you can push the system. Record the animation shown on the screen, for instance using Windows + G, and attach it to your report.
- Question 2: Demonstrate what happens if you increase the length of the pendulum? Compare the overshoot and settling times of two different lengths, by presenting proper graphs and analysing them.
- Conclusions & Recommendations
- Appendix: Program Listing (the simulation file).
- Report file name convention:
- Report_[Section#]_[Student_ID]_ [Last_Name}_[First_Name]_LAB1.pdf, e.g.
  Report_09_00099887766_Smith_John_LAB1.pdf
- Your code also should be submitted in a zip file, if more than one file needs to be submitted. Otherwise submit the code unzipped.
- Code file name convention:
  Code_[Section#]_[Student_ID]_[Last_Name}_[First_Name]_LAB1.pdf, e.g.
  Code_09_00099887766_Smith_John_LAB1.[c, zip]

- Lab reports are due in 1 week since your lab session starts.
- Submit to D2L→ Assessment → Assignment → Lab6
- Late submissions will be penalized at a rate of 10% per day, where weekends count as two days for online submission
- Each student should submit his/her own individual report/work. This is not group work.
- Lab attendance is mandatory. If you submit a report without attending the lab, you will get zero marks.
- Weight:
  - 50%: TA confirms that you did the lab during the lab hour
  - 50%: Lab report and the code