DESCRIPTION:

This directory contains the controller (with associated Simulink and MATLAB files) for the experiment called:

SeeFlex

The SeeFlex uses a system made of either one IP02 with LFJC(-PEN)-E and Seesaw-E or one IP01 with LFJC(-PEN)-E and Seesaw (with potentiometer). It also contains:

There are two encoders on the IP02 Cart. Each encoder is 1024 counts/revolution or 4096 counts/revolution in quadrature.

There is one encoder on the Seesaw_E module. This encoder is 1024 counts/revolution or 4096 counts/revolution in quadrature.

There is one encoder on the LFJC-E module. This encoder is 1024 counts/revolution or 4096 counts/revolution in quadrature.

If you are using the LFJC-PEN-E module, then there are two encoders on the Cart. Each encoder is 1024 counts/revolution or 4096 counts/revolution in quadrature.

SETUP:

Please refer to the two Figures below:

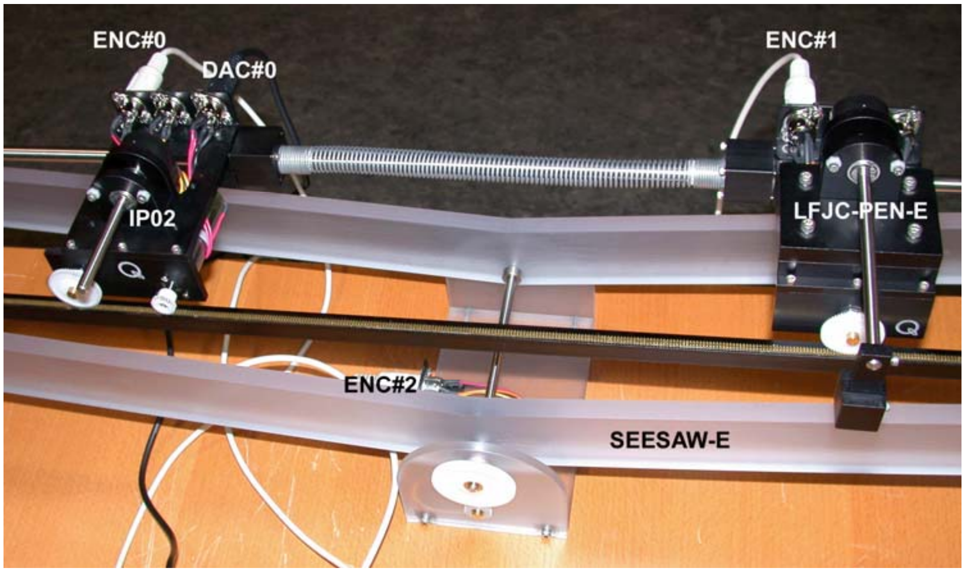


Figure 1 – SeeFlex-E System: IP02 + SEESAW-E + LFJC-PEN-E

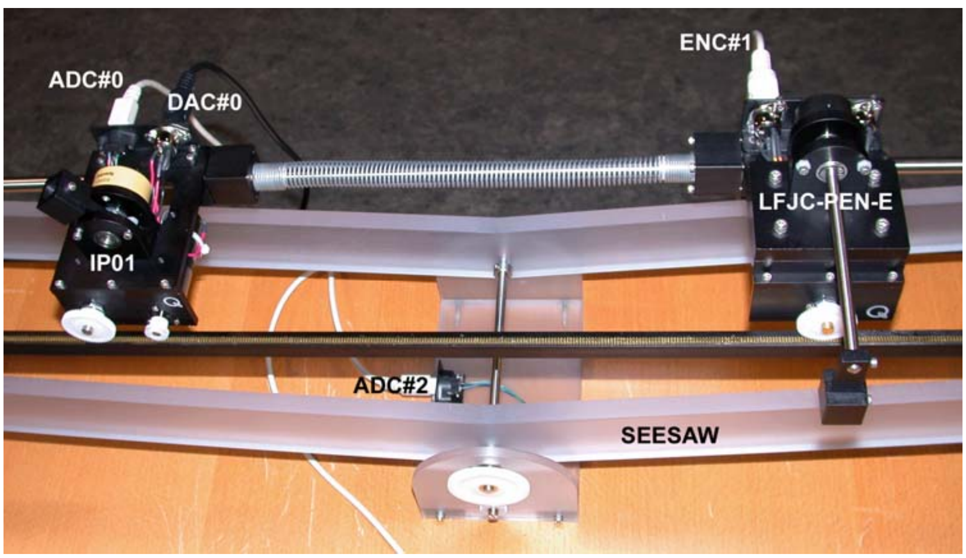


Figure 2 – SeeFlex System: IP01 + SEESAW + LFJC-PEN-E

SeeFlex-E (With Encoders) Configuration

The SeeFlex-E configuration is depicted in Figure 1. Connect the LFJC(-PEN)-E module to the IP02 with the setscrews supplied. The IP02 system should be placed on top of the Seesaw-E so that the Seesaw-E instrumented fulcrum gear is facing the same side as the IP02 and LFJC(-PEN)-E pinions, for example towards you.

The additional mass that is supplied with your IP02 SHOULD NOT BE ATTACHED for this experiment. The sample controller provided is designed to operate without it. You may add the weight to alter the system dynamics.

In the case of the SeeFlex-E configuration, as shown in Figure 1, the IP02 Drive Cart Position is measured via Encoder Channel #0 (i.e., ENC#0). The LFJC(-PEN)-E Drive Cart Position is measured via Encoder Channel #1 (i.e., ENC#1). The Seesaw-E Angle is measured via Encoder Channel #2 (i.e., ENC#2).

Attach a cable from "To Load" of the UPM to the motor of the driving cart (i.e., IP02). Drive the "From D/A" of that power module from D/A #0 (DAC#0) on the Q4 or Q8.

Using the 5-pin DIN cables supplied, connect the cables appropriately.

SeeFlex (With Potentiometers) Configuration

The SeeFlex configuration is depicted in Figure 2. Connect the LFJC(-PEN)-E module to the IP01 with the setscrews supplied. The IP01 system should be placed on top of the Seesaw so that the Seesaw instrumented fulcrum gear is facing the same side as the IP01 and LFJC(-PEN)-E pinions, for example towards you.

In the case of the SeeFlex configuration, as shown in Figure 2, the IP01 Drive Cart Position is measured via Analog Input Channel #0 (i.e., ADC#0). The LFJC(-PEN)-E Drive Cart Position is measured via

Encoder Channel #1 (i.e., ENC#1). The Seesaw Angle is measured via Analog Input Channel #2 (i.e., ADC#2).

Attach a cable from "To Load" of the UPM to the motor of the driving cart (i.e., IP01). Drive the "From D/A" of that power module from D/A #0 (DAC#0) on the Q4 or Q8.

OPERATION:

With the computer OFF, ensure that the Q4 (or other DAC) is properly installed in the PC.

Turn the computer ON.

Turn the Power Module ON.

Ensure all cables are properly connected.

Ensure that the red LED (Light Emitting Diode) on the Q4 or Q8 Terminal Board is lit.

> If it is not lit, you must check the small green (or yellow) fuse that is located on the Terminal Board. Replace it as required. It is a 1 Ampere field replaceable fuse. Manufacturer: Bussman Part No.: MCR-1.
>
> Fuse Specification:
> http://www.bussmann.com/PRODUCTS/Electronic/Group2.html
> http://www.bussmann.com/Library/BifDocs/2003.pdf
>
> Resellers:
> http://www.bussmann.com/World/World.html

Run D_SEEFLEX.M to setup the control parameters and compile for WinCon either the q_ip02_sswe_lfjce_seeflex_q4.mdl (assuming a Q4 card) model if you have the SeeFlex-E configuration (as depicted in Figure 1) or the q_ip01_ssw_lfjce_seeflex_q4.mdl model if you have the SeeFlex configuration (as depicted in Figure 2).

Center the driving cart (i.e., either IP01 or IP02) plus LFJC(-PEN)-E module system on the Seesaw(-E). Adjust their position until the Seesaw is properly balanced.

Click START the above conditions have been satisfied.

Watch and Learn!

If it starts to go unstable, click STOP or the 'Pause / Break' Button.

Thank you,

For additional information, please refer to the accompanying manuals or contact us at:

support@quanser.com
Tel: +1 905.940.3575
fax: +1 905.940.3576

Remember to include ALL information such as:

Computer OS and Processor Speed and Type.
All Software Versions.
The names of all the controller files being used.
The type of DACB you are using and the number of encoders.

This will help us to resolve the difficulties you may be experiencing.

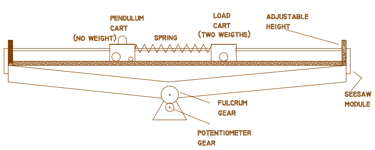
Sincerely,

Quanser Consulting Inc.

3.6.1 DESCRIPTION

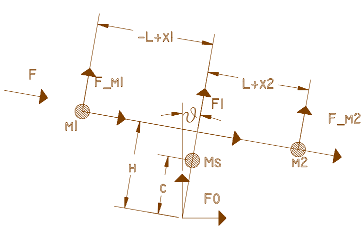
This experiment is a variation on the Seesaw experiment. It combines the two masses and a spring with the seesaw experiment to obtain a sixth order system. The purpose of the experiment is to design a controller that balances the seesaw.

In order to assemble the system, you must first assemble the linear flexible joint as described in section 3.2. You then mount the structure on the seesaw as in the seesaw experiment to obtain the system shown in Figure LFJS1.



3.6.2 MATHEMATICAL MODEL

Consider the simplified diagram of figure LFJS2 and the following definitions for the coordinate frames of interest.



The kinetic and potential energies of the moving elements are obtained as follows:

Consider the coordinate frames defined in Figure LFJS2. Using transformation matrices we have the following transformations:

$$T^{01} = \begin{bmatrix} \cos(\theta) & 0 & -\sin(\theta) & h\sin(\theta) \\ 0 & 1 & 0 & 0 \\ \sin(\theta) & 0 & \cos(\theta) & h\cos(\theta) \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T^{1m1} = \begin{bmatrix} 1 & 0 & 0 & -\frac{L}{2} + x_1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T^{1m2} = \begin{bmatrix} 1 & 0 & 0 & \frac{L}{2} + x_2 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The last column in each matrix represents the position of the frame relative to the previous frame.

The transformation $T^{m}1 = T^{01} T^{1m1}$ represents the position and orientation of the motor cart relative to the base frame and $T^{m}2 = T^{01} T^{1m2}$ is the position and orientation of the load cart attached relative to the base frame.

Defining

$$T^{01} T^{1m1} = \begin{bmatrix} & & & P_m 1^{x} \\ & [R^{m}1] & & 0 \\ & & & P_m 1^{z} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(Note that there is no motion along the 'y' direction).

Then, the kinetic energy of the motor cart is given by:

and the potential energy of the motor cart is given by:

$$PE_m 1 = M_1\, g\, P_m 1^z$$

similarly for the load cart we have :

Defining

$$T^{01}\,T^{1\,m2} = \begin{bmatrix} & & & P_m 2^x \\ & [R^m 2] & & 0 \\ & & & P_m 2^z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Then, the kinetic energy of the load cart is given by:

$$KE_m 2 = 0.5\, M_2 \left(\left[\frac{\delta\, P_m 2^x}{\delta t} \right]^2 + \left[\frac{\delta\, P_m 2^z}{\delta t} \right]^2 \right)$$

and the potential energy of the motor cart is given by:

$$PE_m 2 = M_2\, g\, P_m 2^z$$

The potential energy in the spring

$$PE_{spring} = 0.5\, K\, (x_1 - x_2)^2$$

The kinetic energy of the cart is given by:

$$KE_{seesaw} = 0.5\, J_s\, \dot{\theta}^2$$

while the potential energy of the seesaw is:

$$PE_{seesaw} = 0.5\, M_s\, g\, c \cos(\theta)$$

$$KE_m 1 = 0.5\, M_1 \left(\left[\frac{\delta\, P_m 1^x}{\delta t} \right]^2 + \left[\frac{\delta\, P_m 1^z}{\delta t} \right]^2 \right)$$

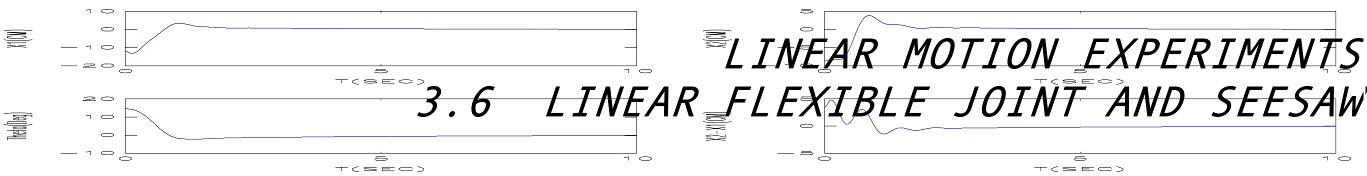
All the above equations are implemented in the MAPLE program SEEFLEX.MAP. The program computes the Lagrangian about each independent axis and derives the nonlinear differential equations. The nonlinear differential equations are written to disk. The program also linearizes the differential equations about the operating point (0,0,0). The linearized model results in the matrix equation:

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{\theta} \\ \ddot{x}_1 \\ \ddot{x}_2 \\ \ddot{\theta} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ a_{41} & a_{42} & a_{43} & 0 & 0 & 0 \\ a_{51} & a_{52} & a_{53} & 0 & 0 & 0 \\ a_{61} & a_{62} & a_{63} & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \theta \\ \dot{x}_1 \\ \dot{x}_2 \\ \dot{\theta} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ b_4 \\ b_5 \\ b_6 \end{bmatrix} F$$

The entries in the matrices are too complex to be included here but are derived in SEEFLEX.MAP and d written to the file SEEF_M.M which is later used in MATLAB to design the controller.

3.7.3 CONTROL SYSTEM DESIGN

Substituting system parameters into the matrix equation we obtain:



$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{\theta} \\ \ddot{x}_1 \\ \ddot{x}_2 \\ \ddot{\theta} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ -66.6 & 62.9 & 9.22 & 0 & 0 & 0 \\ 58.4 & -62.1 & 9.22 & 0 & 0 & 0 \\ 12.8 & 13.6 & 4.1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \theta \\ \dot{x}_1 \\ \dot{x}_2 \\ \dot{\theta} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1.73 \\ 0.04 \\ -0.3 \end{bmatrix} F$$

The force input must be converted to a voltage input since the motor is driven by a voltage (see section 3.1.2):

$$F = \frac{\tau}{r} = \frac{K_m K_g I_m}{r} = \frac{K_m K_g}{Rr} V - \frac{K_m^2 K_g^2}{R r^2} \dot{x}$$

The purpose for the integrator is the following: Since the two masses are not exactly equal and since you will be calibrating the zero for the two masses by hand, there will be constant disturbances in the system which will result in a steady state error in θ. The integrator for θ will eliminate the steady state error.

An LQR controller is designed using the program SEEFLEX.M. The Q and r weighting factors chosen are:

$$Q = diag\,(1000\ 1000\ 3000\ 0\ 0\ 0\ 300)$$

$$r = 20$$

resulting in the feedback gains:

$$K = \begin{bmatrix} 67 & 30 & 56 & 5.8 & 7.9 & 16.3 & 3.8 \end{bmatrix}$$

for units in metres and radians.

$$K = \begin{bmatrix} .67 & .30 & .98 & .06 & .08 & .28 & .07 \end{bmatrix}$$

for units in cm and degrees

The closed loop eigenvalues for the above gain are:

substituting parameter values into the matrix equation and introducing an integrator for θ results in:

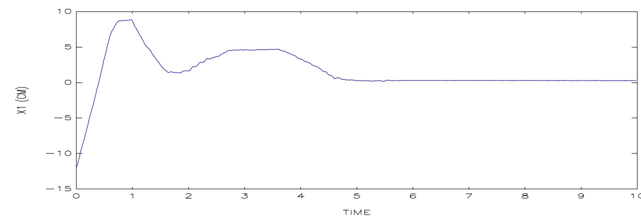
$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{\theta} \\ \ddot{x}_1 \\ \ddot{x}_2 \\ \ddot{\theta} \\ \dot{\zeta} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ -66.6 & 62.9 & 9.22 & -13.5 & 0 & 0 & 0 \\ 58.4 & -62.1 & 9.22 & -0.33 & 0 & 0 & 0 \\ 12.8 & 13.6 & 4.1 & 2.4 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \theta \\ \dot{x}_1 \\ \dot{x}_2 \\ \dot{\theta} \\ \zeta \end{bmatrix} +$$

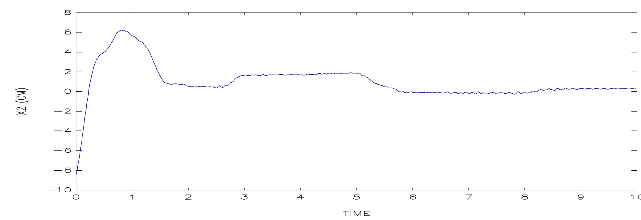
[-1.8 ± j 9.1], [-2.9 ± j 3.3],-8.5,-4.4,-.26

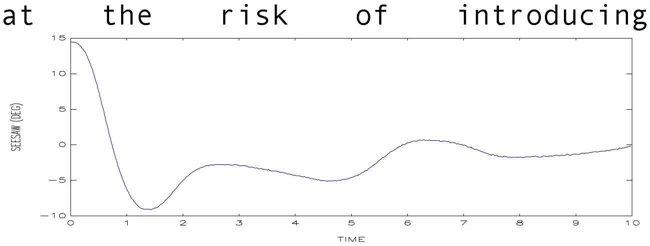
Figure LFJS4 shows the response of the simulated system to an initial condition Xi = [-12, -8.5, 14.4, 0, 0, 0] (cm. and Degrees).

3.7.4 RESULTS

The above controller was implemented on the actual system and figures LFJS5, LFJS6 and LFJS7 show the response to the initial condition simulated using the linear model. The system is stable and behaves generally like the predicted model. There is however a limit cycle due to friction and a steady state error due to non-exact zero positions. The average steady state error is slowly reduced thanks to the integrator but the limit cycle cannot be completely eliminated. The amplitude of the limit cycle may be reduced by increasing the gain in the system but at the risk of introducing instability.







NOTES ON STARTING THE SYSTEM:

a) start the controller program with the motor turned off.
b) slide the masses such that the spring is approximately centered and hold the seesaw horizontal. Make sure the potentiometers do not reach physical limits in the range of motion of the carts
c) hit the letter ‘z’. This takes the present measurements as zero.
d) hit ‘o’, this starts the controller.
e) when the system is balanced and the seesaw is at zero degrees approximately (the integrator should be turned on), hit the letter ‘z’ again. Since the seesaw angle is approximately zero, the positions x1 and x2 are now in the correct ‘zero’ position. Hitting ‘z’ also resets the integrator to zero.
f) to study the disturbance response, push the seesaw slowly to one end while the controller is running and let go. (This is how the initial conditions were obtained for the above plots.

Reference on transformation matrices

Richard P. Paul **Robot manipulators: Mathematics, Programming and Control.** The MIT Press, 1981.