TÉCNICO LISBOA

Computer Control

Project Presentation

Authors
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Model Estimation

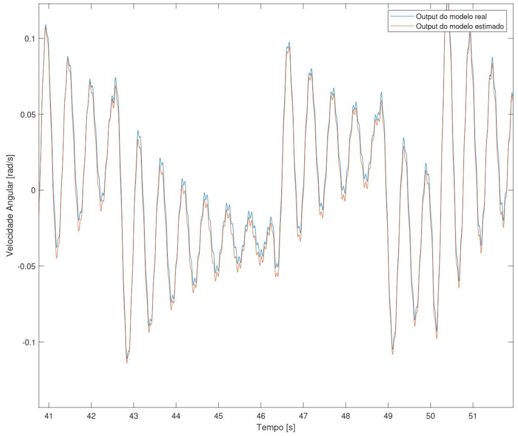
ARMAX Parameters

$n_a = 5$ $n_b = 5$

$n_c = n_a$ $n_k = 1$

Validation

PRBS B=0.008

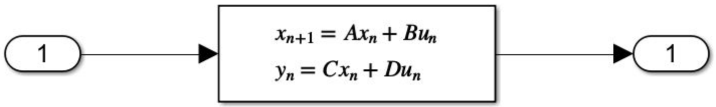


Simulation Parameters

Ts = 0.01 s

ARMAX Model

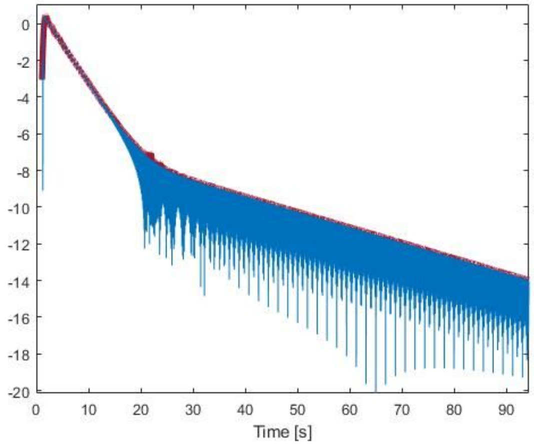
Estimation Technique



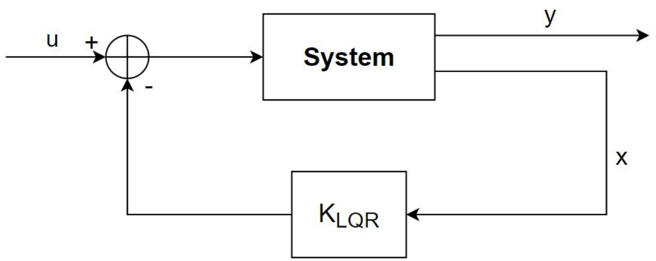
LQR Implementation

Evaluate the envelope of the output

Eigenvalue confirmation - R = 50



$$Slope = -0.0842$$



$$u(k) = -K_{LQR}x(K)$$

$$J = \frac{1}{2}\sum_{k=0}^{\infty}[x^T(k)Qx(k) + Ru^2(x)]$$

Solve Riccati Equation

$$S = A^T\left[S - SB^TBS\frac{1}{R}\right]A + C^TC$$

$$K_{LQR} = (R - B^TSB)^{-1}B^TSA$$

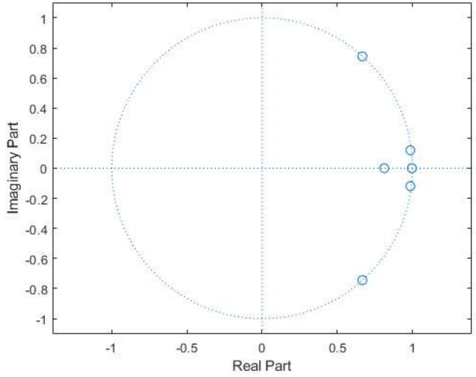
LQR Implementation

Evaluate the envelope of the output

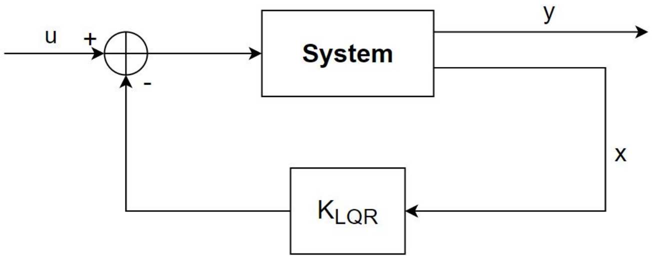
Eigenvalue confirmation - R = 50

Theoretical Pole location

$$0.6669 \pm 0.7440i$$
$$0.9958$$
$$0.9863 \pm 0.1192i$$
$$0.8122$$



$$max(|\lambda_i|) = 0.9992$$

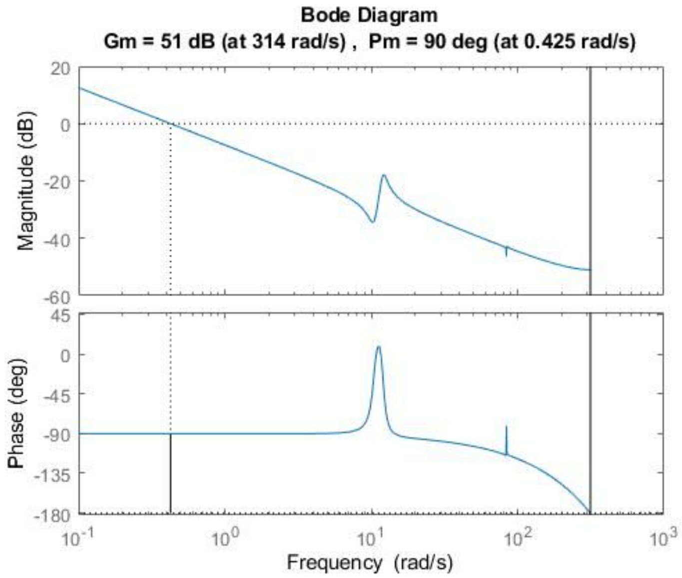


$$m \approx \frac{log(max\{|pole|\})}{T_s}$$

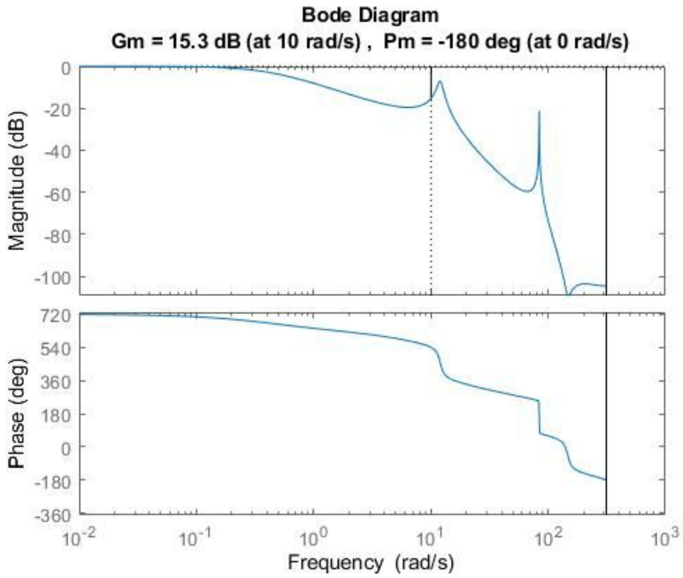
$$error = 4.8963 \cdot 10^{-7}\%$$

LQR Implementation

Open loop Bode Diagram for LQR Control



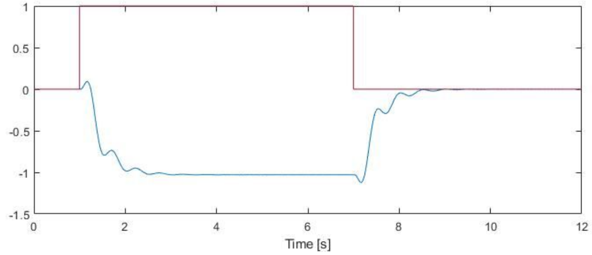
Close Loop Bode Diagram for LQR Control

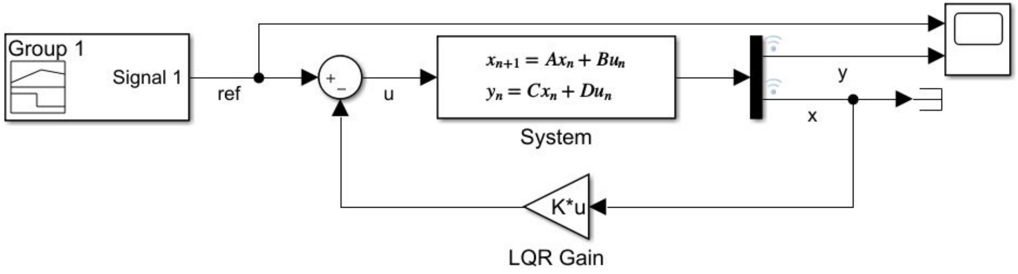


The close loop bode diagram has the reference tracking gain already

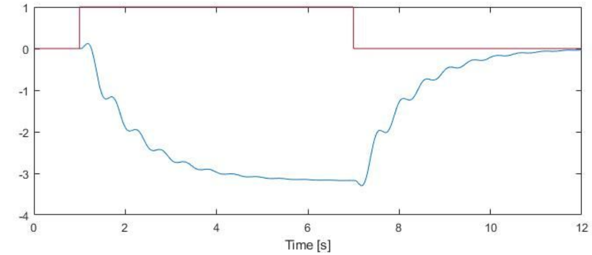
LQR Implementation

R=1

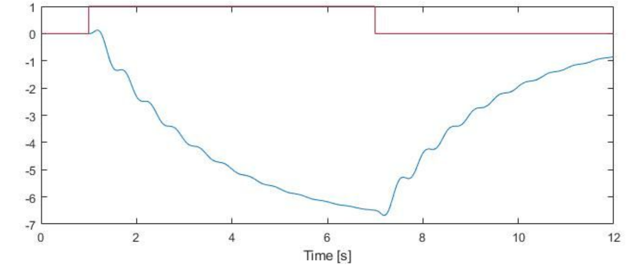




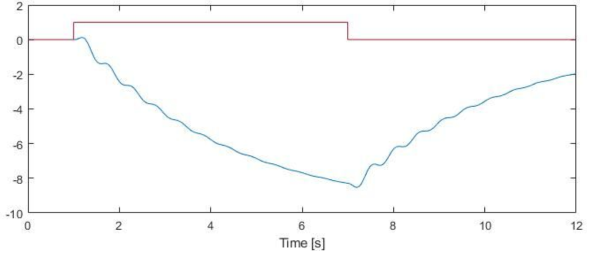
R=10



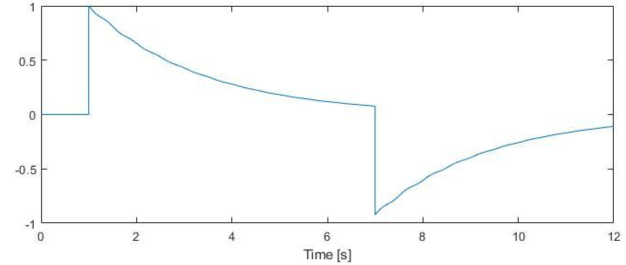
R=50



R=100



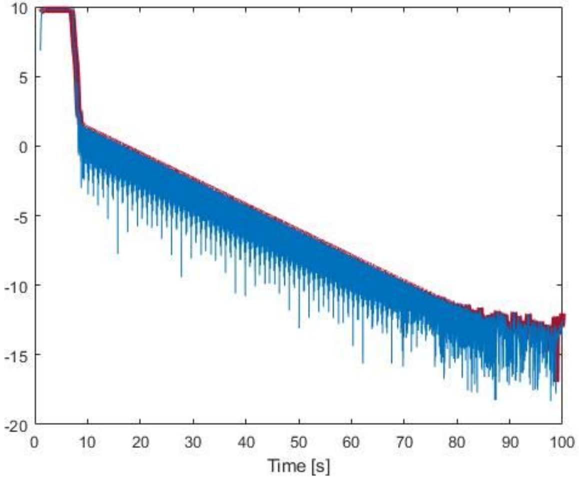
Tensão de entrada (V)



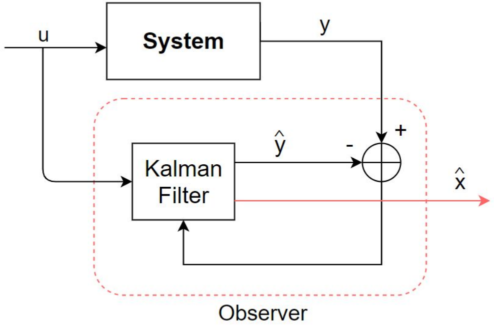
LQE Implementation

Evaluate the envelope of the output

Eigenvalue confirmation - Re = 0.1



$$Slope = -0.1550$$



$$x(k+1) = Ax(k) + Bu(k) + B_1 w(k)$$
$$y(k) = Cx(k) + v(k)$$

$$H(M) = E\{||x(k) - \tilde{x}(k)||^2\}$$

$$P = APA^T + Q_e - \frac{APC^T CPA^T}{R_e + CPC^T}$$
$$M = APC^T(R_e + CPC^T)^{-1}$$

LQE Implementation

Evaluate the envelope of the output

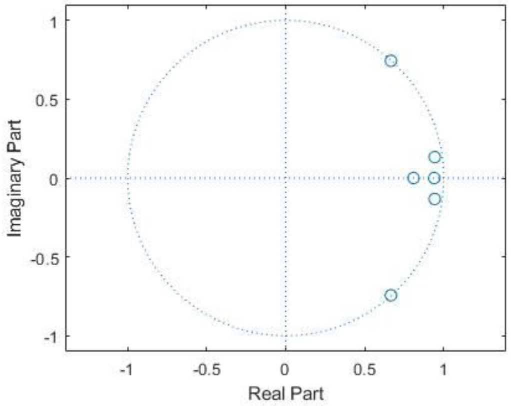
Eigenvalue confirmation - Re = 0.1

$$0.6662 \pm 0.7433i$$

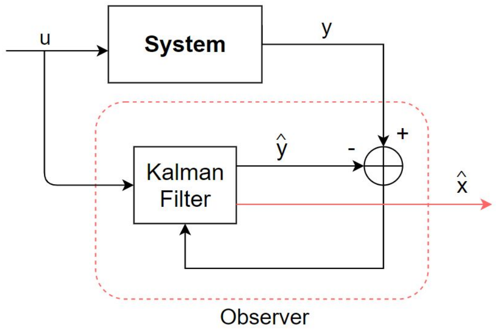
$$0.9400$$

$$0.9430 \pm 0.1326i$$

$$0.8091$$



$$max(|\lambda_i|) = 0.9982$$

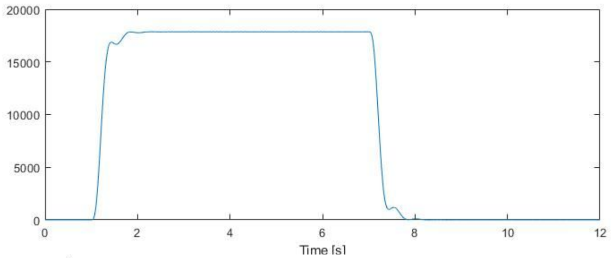


$$m \approx \frac{log(max\{|pole|\})}{T_s}$$

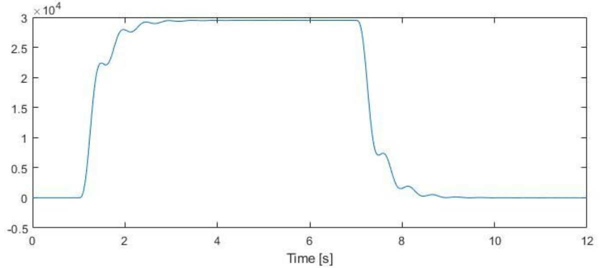
$$error = 0.1842\ \%$$

LQE Implementation

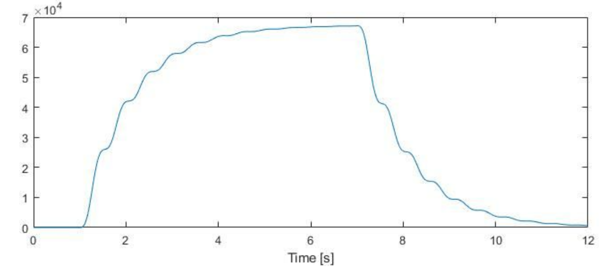
R=0.1

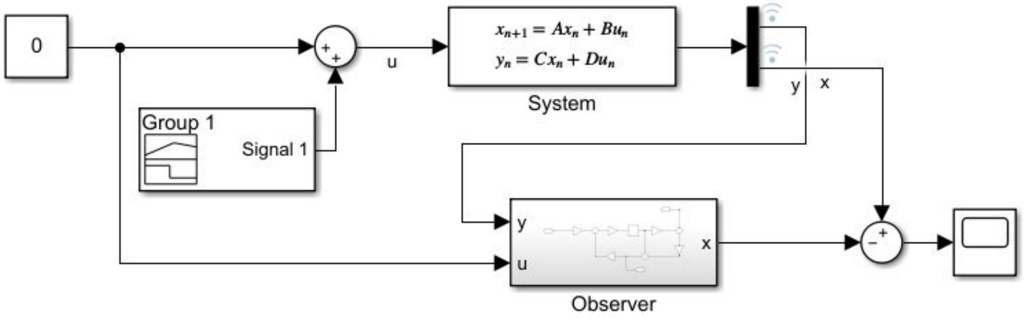


R=1

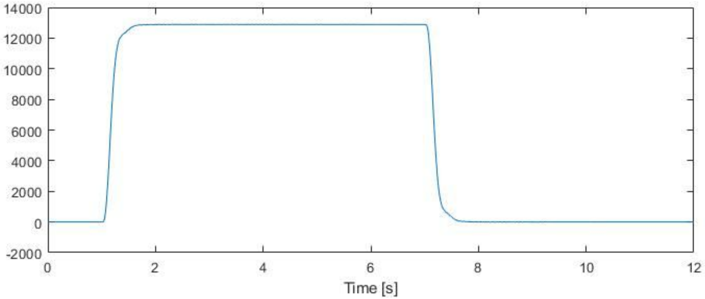


R=10





R=0.01

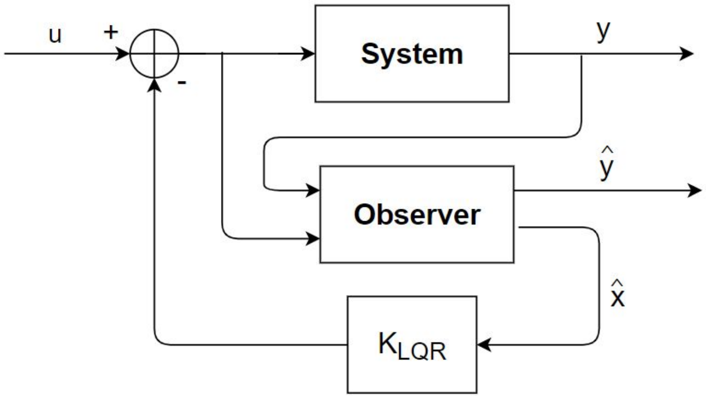


LQG Implementation

Check poles of the closed loop

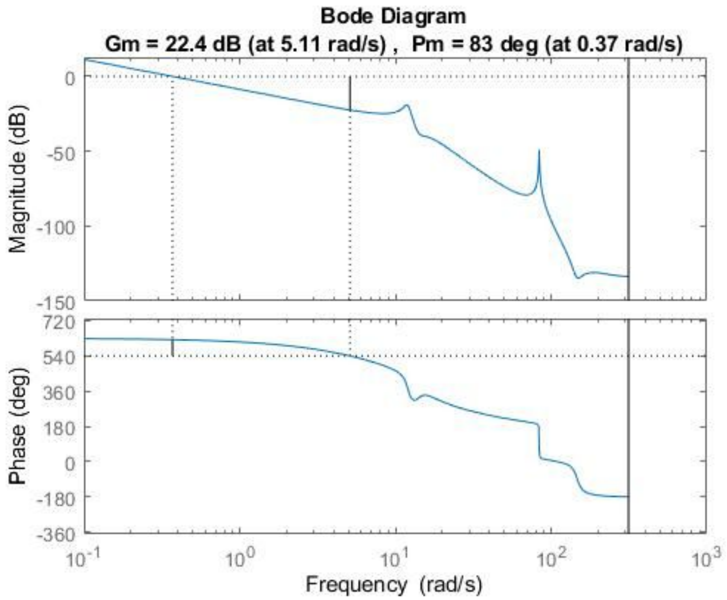
$$0.6662 \pm 0.7433i$$
$$0.6669 \pm 0.7440i$$
$$0.9430 \pm 0.1326i$$
$$0.9863 \pm 0.1192i$$
$$0.9958$$
$$0.8122$$
$$0.9400$$
$$0.8091$$

It is possible to notice the separation principle because the poles of the merge configuration (LQG) are the join poles of the LQR and LQE previously analyzed

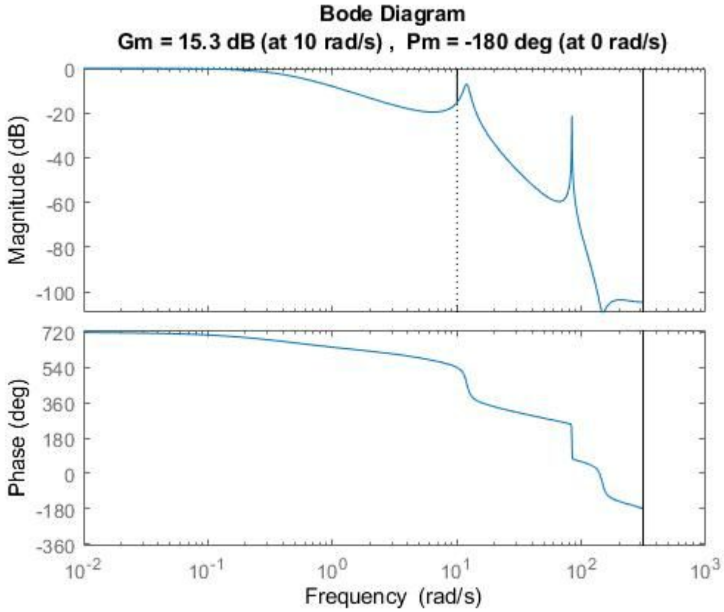


LQG Implementation

Open loop Bode Diagram for LQG Control

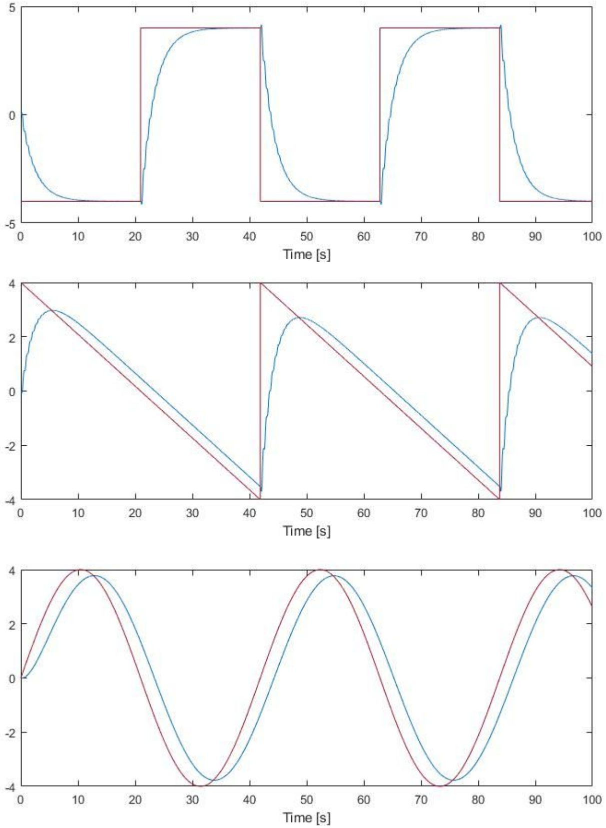


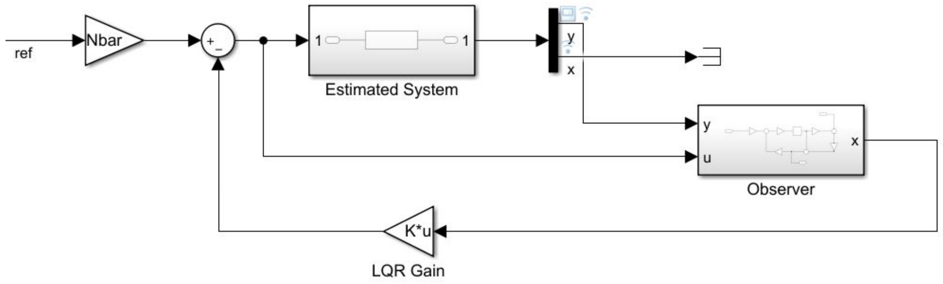
Close Loop Bode Diagram for LQG Control



The close loop bode diagram has the reference tracking gain already

Following Reference Approach

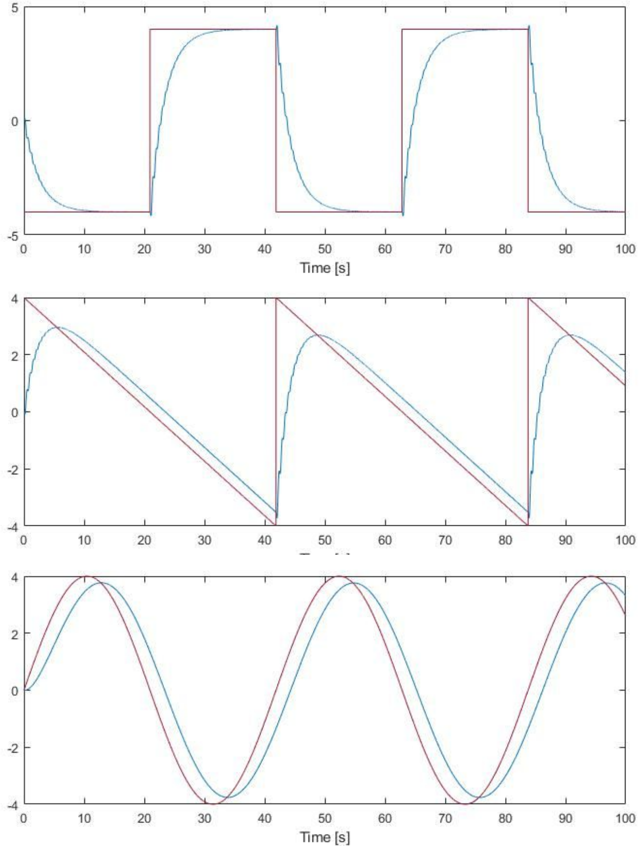




$$\begin{bmatrix} N_x \\ N_u \end{bmatrix} = \begin{bmatrix} A - I & B \\ C & 0 \end{bmatrix}^{-1} \begin{bmatrix} 0 \\ I \end{bmatrix}$$

$$\bar{N} = N_u + K N_x$$

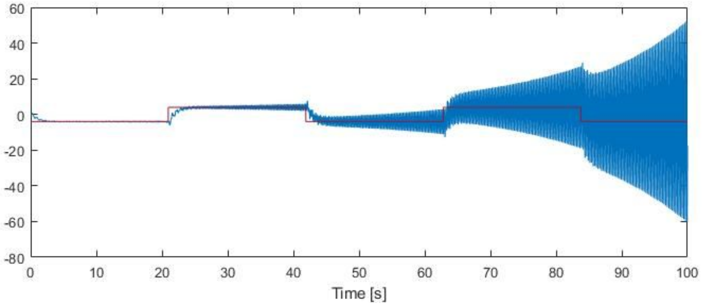
Test on Real System



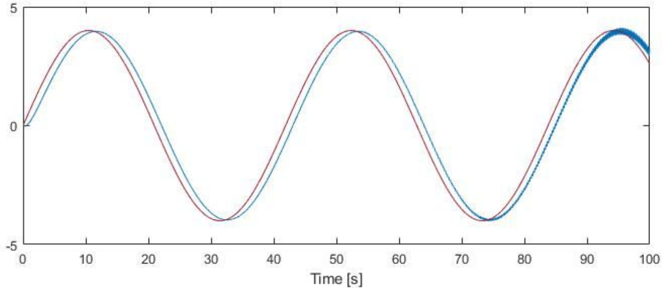
The controller works perfectly with the given real model but it may suffer a from the performance perspective if the real model has disturbances.

Test on Perturbed System

Using the previous control and estimation in a perturbed system



The system is unstable and it seems it is behaving with a high frequency - maybe smoothing the controller (make it a little bit more slower will solve the problem)



Necessity to iterate - approach: be more conservative when choosing R and Re

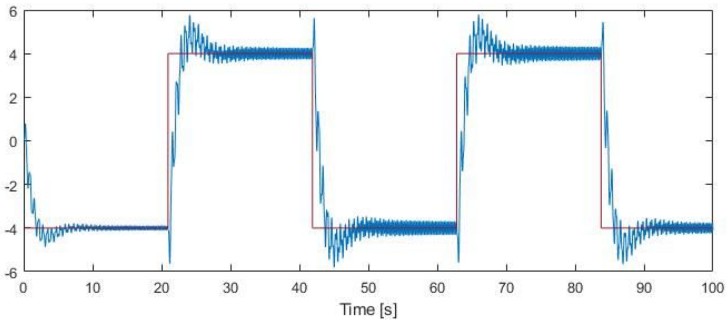
First: Change Re and see if the problem is with the estimation optimization being too rigid

Second: Change R and see if the problem is with the control optimization being too optimistic

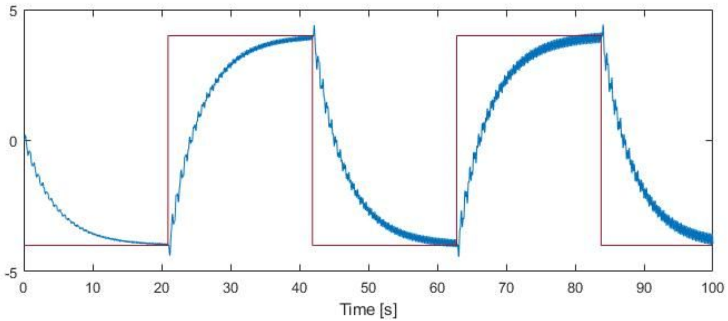
With the sine input the system has a better performance - it made us think the problem with our controller is with the high frequency response

Test on Perturbed System

Re = 20 R = 50



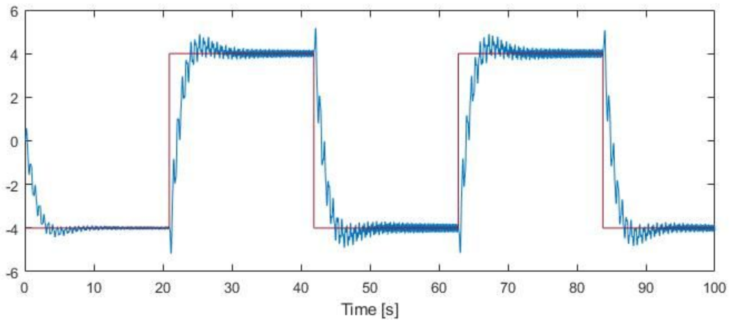
Re = 0.1 R = 800



The previous Graphs correspond to the value of the parameter which we consider the plant to work correctly

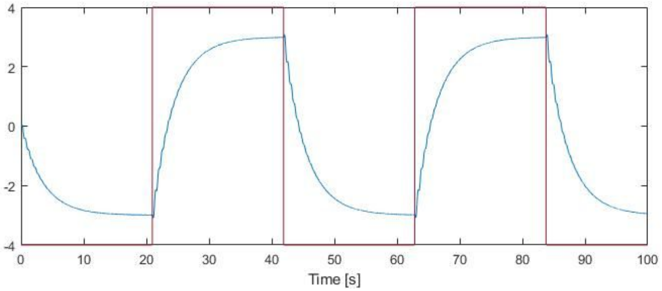
It seems we were too optimistic with the value given to our Re related to the estimation process

Re = 10 R = 100

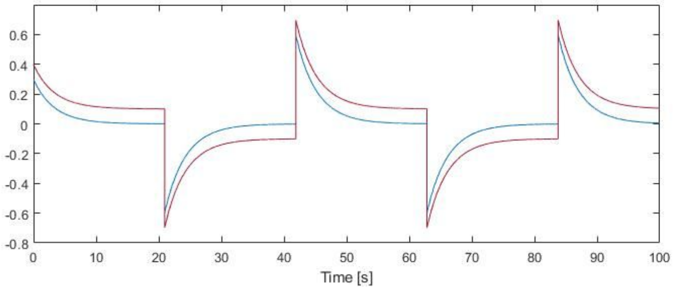


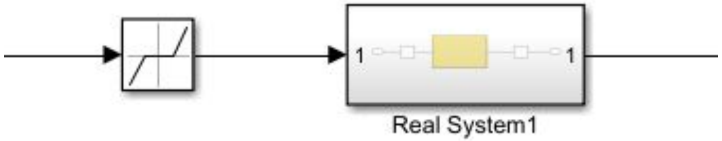
Evaluate Dead Zone Control Dynamic Problem

Output Behaviour



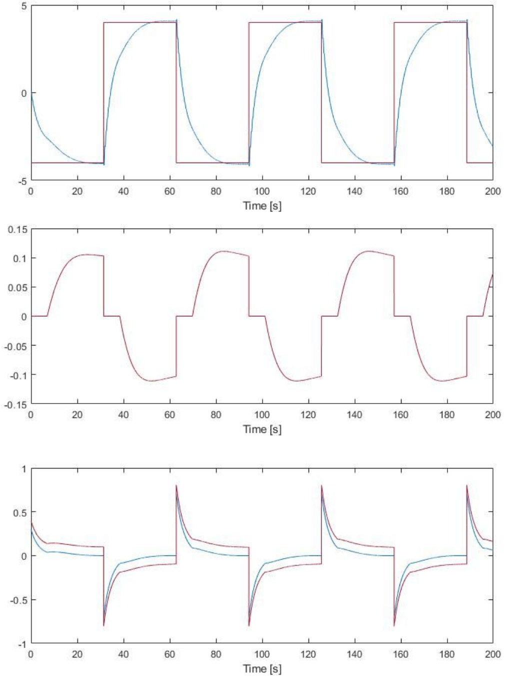
Control Input Behaviour





The current controller is unable to track the reference when the dead zone is present

Evaluate Dead Zone Control Dynamic Problem

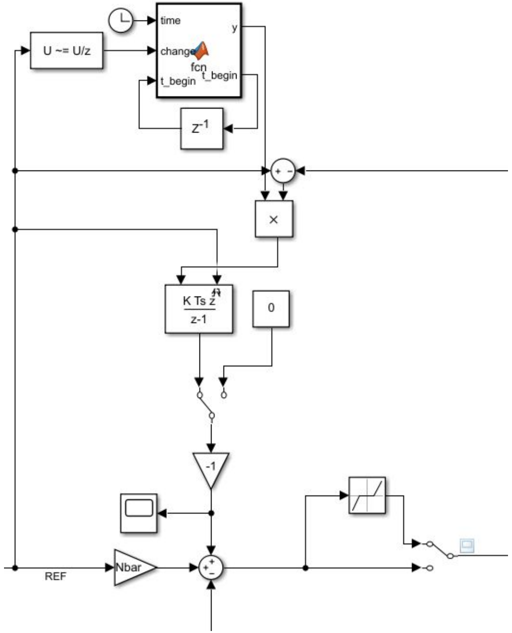


Solution 1

Results from Iterations

$$\Delta t = 7\ s$$

$$K_{integrator} = 0.012$$



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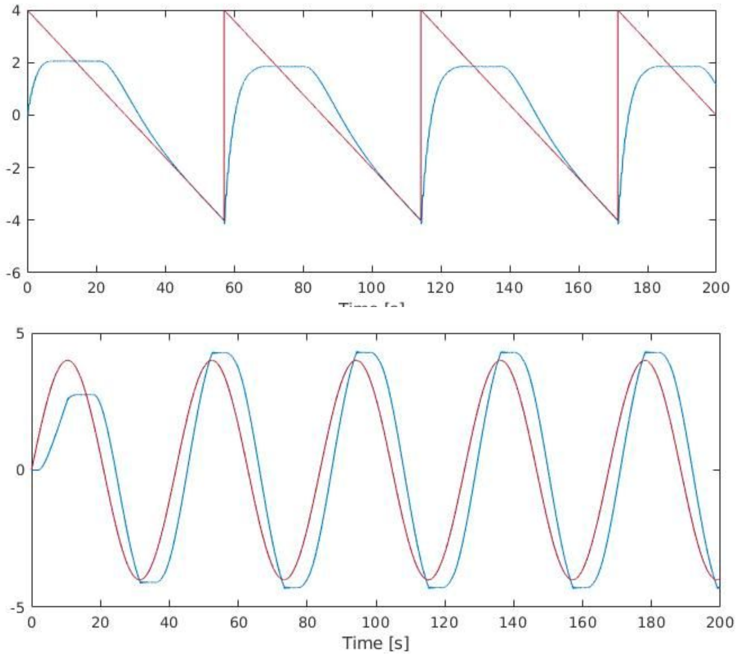
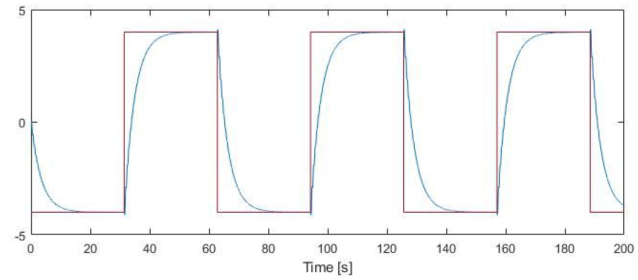
Evaluate Dead Zone Control Dynamic Problem

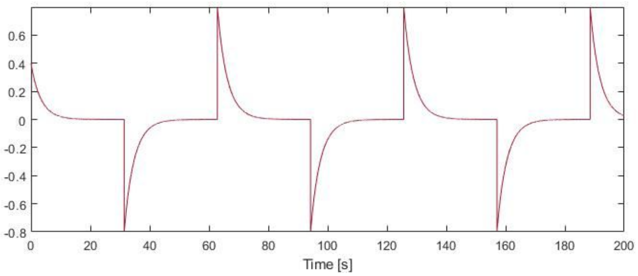
Performance



The previous control method only works good with square wave input

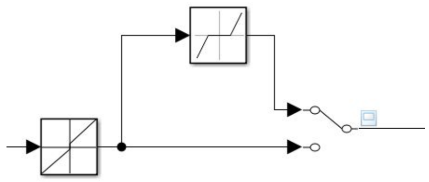
Evaluate Dead Zone Control Dynamic Problem





Solution 2

Invert non linear characteristic



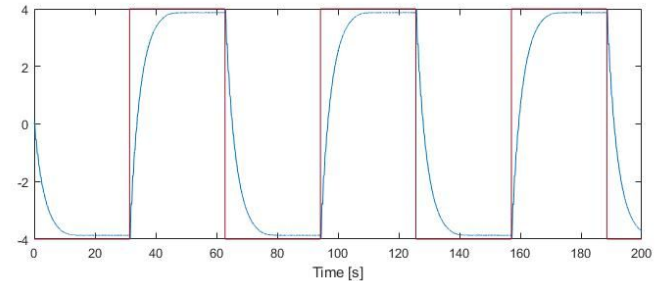
Inversor Characteristic

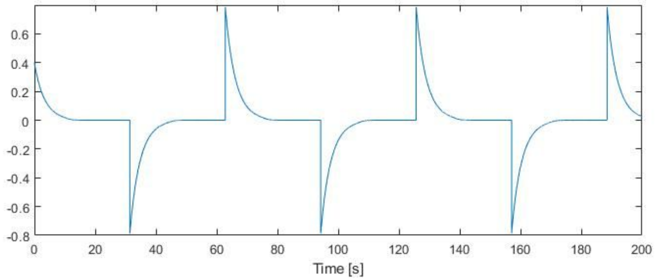
$$y = \begin{cases} u + 0.1, & if\ u > 0 \\ u - 0.1, & if\ u < 0 \end{cases}$$

This approach needs the exact knowledge of the dead zone and a possible problem is the implementation of the non linear block to invert the dead zone

Evaluate Dead Zone Control Dynamic Problem

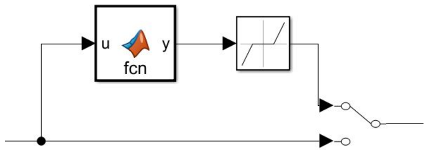
For a = 0.01



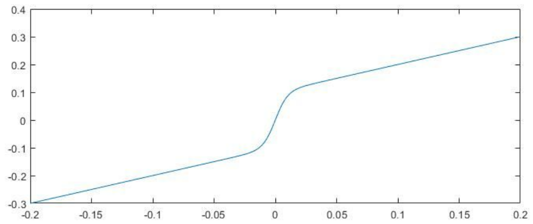


Solution 3

Invert non linear characteristic with differentiable function



Differentiable Pseudo Inverse Characteristic



$$y = \frac{e^{\frac{u}{a}}}{e^{\frac{u}{a}} + e^{-\frac{u}{a}}} \cdot (u + 0.1) + \frac{e^{-\frac{u}{a}}}{e^{\frac{u}{a}} + e^{-\frac{u}{a}}} \cdot (u - 0.1)$$

Q&A Session is Open