State Observer Feedback Control

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Abstract. **Keywords:** First keyword · Second keyword · Another keyword.

1 System Introduction

2 State Observer Feedback control

3 Simulation

Following the "DAVI" guidelines, we do the simulation before implementation. Fig.1 shows the system block diagram made by Matlab and Simulink. Then, we verify our controller by observing the performance of the step response and tracking a 400 Hz sinewave.

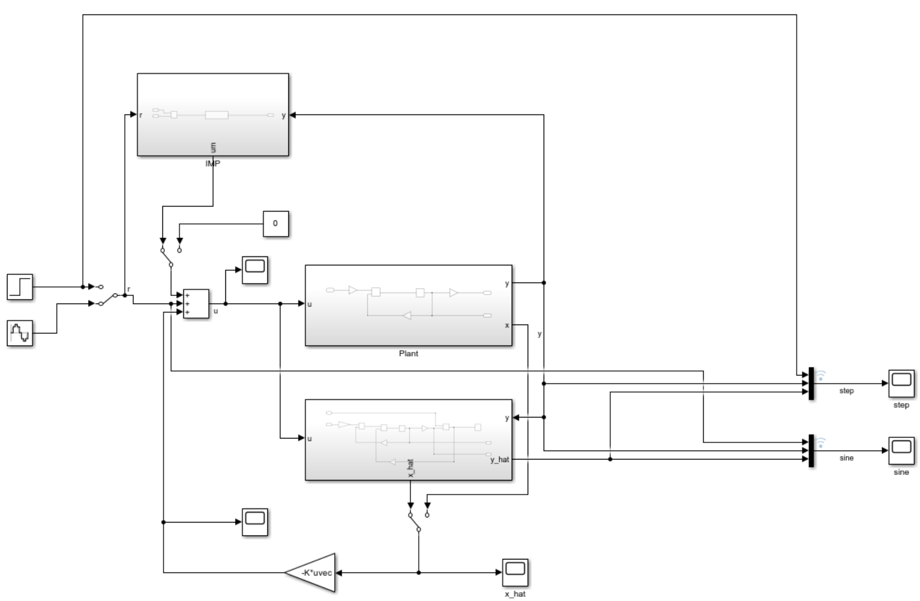


Fig. 1: Sysyem block diagram

3.1 Step response

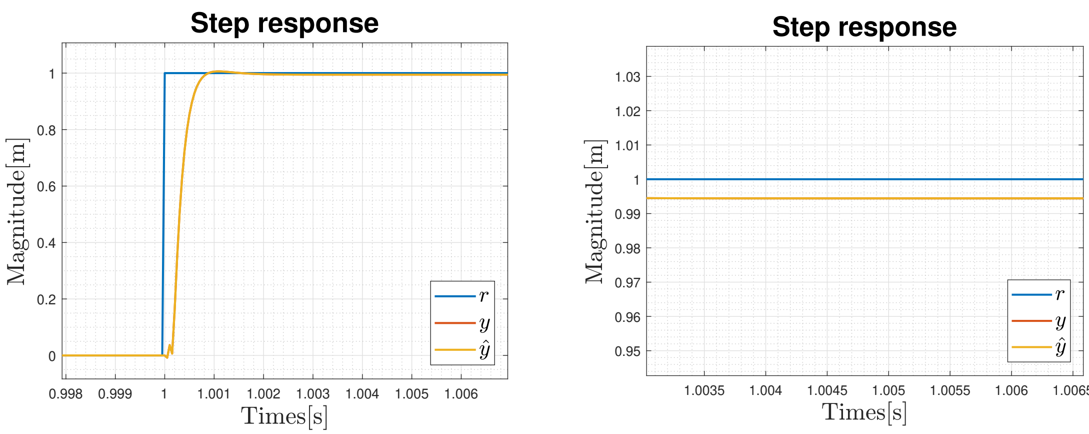
We use the pole placement method to design feedback gain K, the location of poles is assigned at,

$$\text{poles} = \begin{bmatrix} 0.85 \; 0.8 \; 0.1 \; 0.11 \; 0.15 \end{bmatrix} \tag{1}$$

and K is,

$$K = \begin{bmatrix} 0.5450 \; -1.4578 \; 1.4289 \; -0.6525 \; 0.1360 \end{bmatrix} \tag{2}$$

the step response is shown in Fig.2, A steady-state error exists, and it is roughly 0.005.



(a) Step response

(b) Step response : steady state

Fig. 2: Step response

3.2 400 Hz sinewave

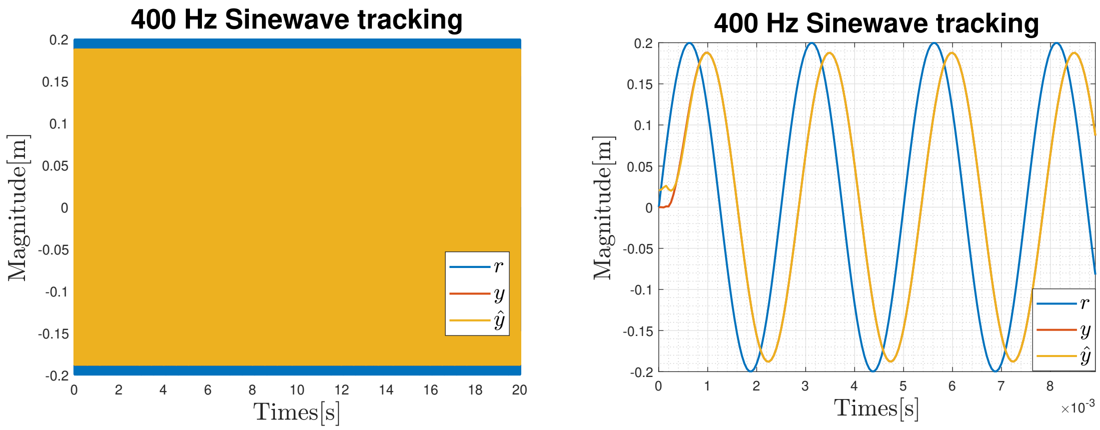
Next, we try to use the same feedback gain K to track a 400 Hz sinewave, and the result is shown in Fig.3 From Fig.4b, the $\hat{y}$ has a slight discrepancy with y initially, resulting from the different initial values between the real system and the state observer. However, the error converges to zero after passing a little time. On the other hand, there is a huge phase delay and a steady state error in our tracking results, as a result, we try to eliminate these phenomena by adding an internal model into our controller. Following the materials provided by the professor, the internal model can be generalized as

$$x_m[k+1] = A_m x_m[k] + B_m[y[k] - r[k]] \tag{3}$$

$$u_m[k] = -K_m x_m[k] \tag{4}$$

our control objective is to track a 400 Hz sinewave, as a result, we add a peak filter at 400Hz

$$A_m = \begin{bmatrix} 0 & 1 \\ -1 & 2cos(\omega_0 T) \end{bmatrix}, B_m = \begin{bmatrix} 0 \\ 1 \end{bmatrix} \tag{5}$$



(a) Sinewave tracking

(b) sinewave tracking: zoom-in

Fig. 3: 400 Hz sinewave tracking

where $\omega_0 = 400/f_s \cdot 2\pi$ is the frequency, and $T = 10^{-5}s$ is the sampling time. The state observer feedback law with internal model is defined in Eqn.(6)

$$u[k] = -K\hat{x}[k] + u_m[k] + r[k] \tag{6}$$

To obtain K and K_m, we augment the plant and internal model,

$$x_{aug}[k] = \begin{bmatrix} x[k+1] \\ x_m[k+1] \end{bmatrix} = \begin{bmatrix} A & 0 \\ B_m C & A_m \end{bmatrix} \begin{bmatrix} x[k] \\ x_m[k] \end{bmatrix} + \begin{bmatrix} B \\ 0 \end{bmatrix} u[k] + \begin{bmatrix} 0 \\ -B_m \end{bmatrix} r[k] \tag{7}$$

$$y[k] = \begin{bmatrix} C & 0 \end{bmatrix} \begin{bmatrix} x[k] \\ x_m[k] \end{bmatrix} \tag{8}$$

$$K_{aug} = \begin{bmatrix} K & K_m \end{bmatrix} \tag{9}$$

By applying the pole placement method again, we assign the location of poles at

$$\text{poles} = \begin{bmatrix} 0.85 & 0.8 & 0.1 & 0.11 & 0.15 & -0.45 & -0.4 \end{bmatrix} \tag{10}$$

we can derive K_{aug}

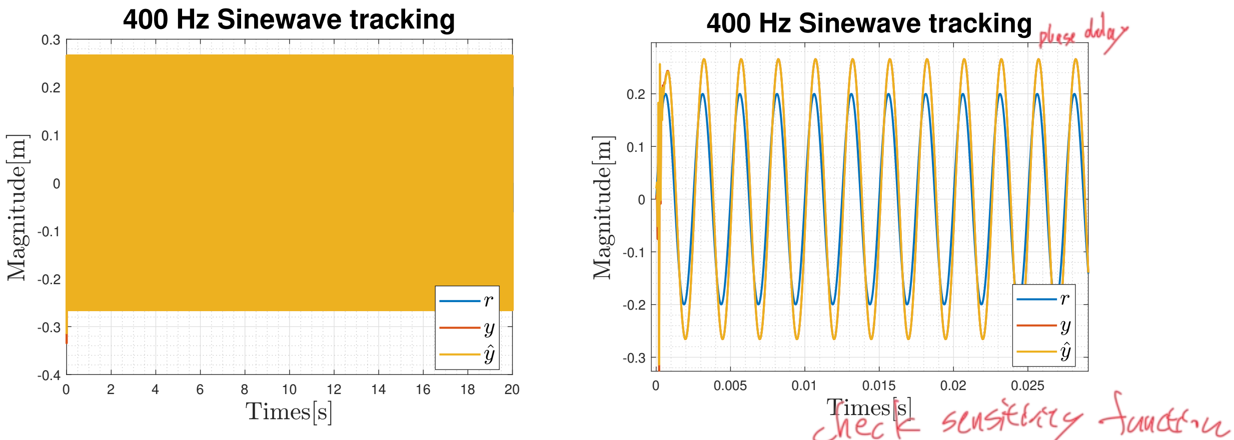
$$K_{aug} = \begin{bmatrix} 3.3950 & -2.1665 & 1.3868 & 1.1696 & -2.5367 - 15.1447 & 17.1860 \end{bmatrix} \tag{11}$$

and then we can also derive K and K_m.

$$K = \begin{bmatrix} 3.3950 & -2.1665 & 1.3868 & 1.1696 & -2.5367 \end{bmatrix} \tag{12}$$

$$K_m = \begin{bmatrix} -15.1447 & 17.1860 \end{bmatrix} \tag{13}$$

Fig.4 shows the tracking result using state observer feedback with the internal model. we can observe that the phase is eliminated aggressively, however, so far we haven't dealt with the steady-state error problem.



(a) Sinewave tracking with internal model (b) sinewave tracking with internal model : zoom-in

Fig. 4: 400 Hz sinewave tracking with internal model

4 Discussion

1. Why did LQR fail? See Fig.5 States don't have physical meaning, then how do we tune Q and R?
2. How to design with IMP, and why is it in this form, see Eqn.(4)? why do we augment it?
3. How to deal with the steady-state error after applying the internal model?
4. If we have 2 different source signals, do we need to design 2 kinds of internal models?

References

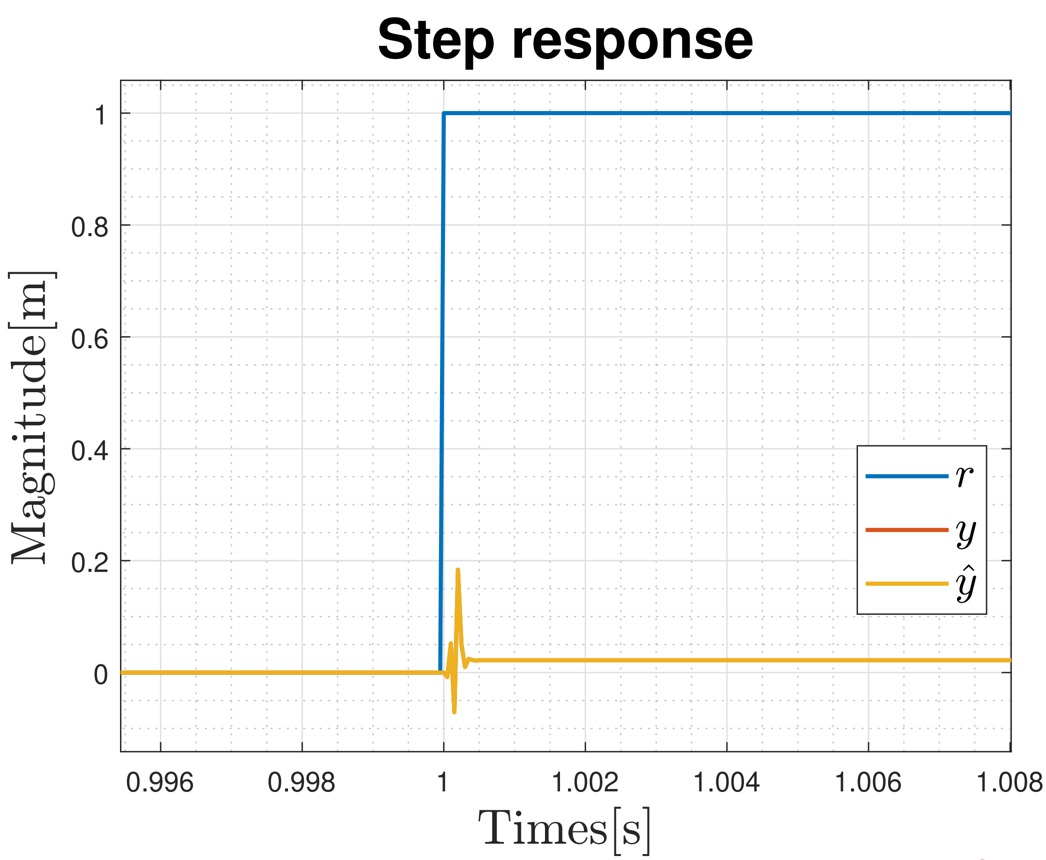


Fig. 5: Step response with LQR : Q=20*eye(5), R = 1

dc gain