

# CHEM-E7190/2024: Exercise 11 Part 2/2 - Luenberger observer [EXTRA] - Solutions

1. Design a Luenberger observer for the following state-space system. Implement the code and simulate the system in Matlab.

$$\begin{aligned}x(k+1) &= \begin{bmatrix} 1.8097 & -0.8187 \\ 1 & 0 \end{bmatrix} x(k) + \begin{bmatrix} 0.5 \\ 0 \end{bmatrix} u(k) \\ y(k) &= [0.1810 \quad -0.1810] x(k) + [0] u(k)\end{aligned}$$

*Hint: First, check the observability of the system by computing the observability matrix. Then, select desired observer poles and use pole placement to compute the observer gain matrix  $L$ .*

2. The dynamic equations of the stirred tank system in state-space form are the following:

$$\begin{aligned}\dot{x}(t) &= \begin{bmatrix} -0.5 & 0 \\ 0 & -1 \end{bmatrix} x(t) + \begin{bmatrix} 1 & 0 & 0 \\ -0.1 & 1 & 1 \end{bmatrix} u(t) \\ y(t) &= \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} x(t) + \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} u(t)\end{aligned}$$

Design a Luenberger observer for the system. Implement the code and simulate the system in Matlab.

*Hint: Since all states are measured (as indicated by the identity matrix in  $C$ ), consider modifying the problem by assuming one state is not measured. Then, compute the observability matrix and design the observer accordingly.*

3. Calculate the observer gains for the following system when the desired characteristic equation is  $(\lambda + 5)(\lambda + 10)$

$$\begin{aligned}\dot{x}(t) &= \begin{bmatrix} -1 & 1 \\ 2 & -4 \end{bmatrix} x(t) + \begin{bmatrix} 1 \\ 0 \end{bmatrix} u(t) \\ y(t) &= [1 \quad 0] x(t)\end{aligned}$$

*Hint: Verify observability by constructing the observability matrix. Then, set up the characteristic equation of  $(A - LC)$  and equate it to the desired characteristic equation to solve for the observer gains*

$$L = \begin{bmatrix} l_1 \\ l_2 \end{bmatrix}.$$

*Solution*

**Observability**

$$\begin{aligned}CA &= [1 \quad 0] \begin{bmatrix} -1 & 1 \\ 2 & -4 \end{bmatrix} = [-1 \quad 1] \\ O &= \begin{bmatrix} C \\ CA \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -1 & 1 \end{bmatrix} \text{rank}(O) = 2 = N_o\end{aligned}$$

**Characteristic equation**

$$\begin{aligned}A - LC &= \begin{bmatrix} -1 & 1 \\ 2 & -4 \end{bmatrix} - \begin{bmatrix} l_1 \\ l_2 \end{bmatrix} [1 \quad 0] = \begin{bmatrix} -1-l_1 & 1 \\ 2-l_2 & -4 \end{bmatrix} \\ |\lambda I - (A - LC)| &= \begin{vmatrix} \lambda + 1 + l_1 & -1 \\ -2 + l_2 & \lambda + 4 \end{vmatrix} \\ (\lambda + 1 + l_1)(\lambda + 4) - (-1)(-2 + l_2) &= \lambda^2 + (5 + l_1)\lambda + 4(1 + l_1) + l_2 - 2\end{aligned}$$

# Luenberger Chapter 2 Exercise Answer

**Wolfgang Guggemos**

A red circular graphic with a gradient, appearing as a semi-circle or a partial circle, located to the right of the author's name.

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