

**Problem 1.** (Transformation to controllable canonical form). Consider the following third-order SISO LTI system

$$\dot{x} = Ax + Bu, \quad x \in \mathbb{R}^3, u \in \mathbb{R}^1 \quad (\text{AB-CLTI})$$

Assume that the characteristic polynomial of  $A$  is given by

$$\det(sI - A) = s^3 + \alpha_1 s^2 + \alpha_2 s + \alpha_3$$

and consider the  $3 \times 3$  matrix

$$T := C \begin{bmatrix} 1 & \alpha_1 & \alpha_2 \\ 0 & 1 & \alpha_1 \\ 0 & 0 & 1 \end{bmatrix}$$

where  $C$  is the system's controllability matrix.

(a) Show that the following equality holds:

$$B = T \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

(b) Show that the following equality holds:

$$AT = T \begin{bmatrix} -\alpha_1 & -\alpha_2 & -\alpha_3 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}$$

(c) Show that if the system (AB-CLTI) is controllable, then  $T$  is a nonsingular matrix.

(d) Combining parts (a)–(c), you showed that, if the system (AB-CLTI) is controllable, then the matrix  $T$  given above can be viewed as a similarity transformation that transforms the system into the controllable canonical form

$$T^{-1}AT = \begin{bmatrix} -\alpha_1 & -\alpha_2 & -\alpha_3 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}, \quad T^{-1}B = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}.$$

Use this to find the similarity transformation that transforms the following pair into the controllable canonical form

$$A := \begin{bmatrix} 6 & 4 & 1 \\ -5 & -4 & 0 \\ -4 & -3 & -1 \end{bmatrix}, \quad B := \begin{bmatrix} 1 \\ -1 \\ -1 \end{bmatrix}.$$

# Linear Systems Theory Hespanha Solutions

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