Tutorial 6
ELL-225: Control Engineering

Session: Semester-II (2022-23)

1. A HelpMate transport robot is used to deliver goods in a hospital setting. The robot can deliver food, drugs, laboratory materials, and patients' records (refer to **(1)**). Consider the linearized and simplified state space representation of the same given below:

$$\dot{x} = \begin{bmatrix} \dot{p} \\ \dot{\theta} \\ \dot{v} \end{bmatrix} = \begin{bmatrix} 0 & 0 & -1 \\ 0.05 & -9.9977 & 0 \\ 0 & 4 & -1.0222 \end{bmatrix} \begin{bmatrix} p \\ \theta \\ v \end{bmatrix} + \begin{bmatrix} 1.51 \\ 0.01 \\ 3.042 \end{bmatrix} u$$

where, p is the position of the centre of gravity, θ is the angular position of the wheels, v is the velocity and u is the motor input.

(a) If v is the measured output, what would be the transfer function?

(b) Evaluate the steady state error for unit step and unit ramp inputs.

Figure 1: HelpMate transport robot

2. Large microwave antennas have become increasingly important for radio astronomy and satellite tracking. The antenna servosystem is shown in Fig. (2). The transfer function of the antenna, drive motor, and amplidyne is approximated by

$$G(s) = \frac{\omega_n^2}{s(s^2 + 2\zeta\omega_n s + \omega_n^2)},$$

where $\zeta = 0.707$ and $\omega_n = 15$. The transfer function of the power amplifier is approximately

$$G_1(s) = \frac{k_a}{\tau s + 1},$$

where $\tau = 0.15$ second.

(a) the system is subjected to a disturbance $T_d(s) = \frac{10}{s}$. Determine the required magnitude of k_a in order to maintain the steady-state error of the system less than $0.10°$ when the input $R(s)$ is zero.

(b) Determine the error of the system when subjected to a disturbance $T_d(s) = \frac{10}{s}$ when it is operating as an open-loop system ($k_s = 0$) with $R(s) = 0$.

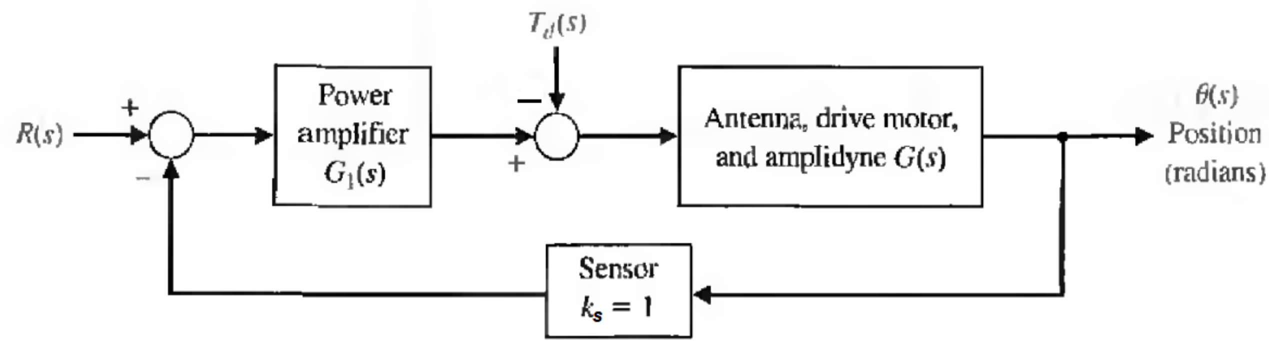

Figure 2: Antenna control system

3. An electric ventricular assist device (EVAD) as shown in Fig. (3) has been designed to help patients with diminished but still functional heart-pumping action to work in parallel with the natural heart. The device consists of a brushless dc electric motor that actuates on a pusher plate. The plate movements help the ejection of blood in systole and sac filling in diastole. System dynamics during systolic mode have been found to be:

$$\begin{bmatrix} \dot{x} \\ \dot{v} \\ \dot{P}_{ao} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & -68.3 & -7.2 \\ 0 & 3.2 & -0.7 \end{bmatrix} \begin{bmatrix} x \\ v \\ P_{ao} \end{bmatrix} + \begin{bmatrix} 0 \\ 425.4 \\ 0 \end{bmatrix} e_m$$

The state variables in this model are x, the pusher plate position; v, the pusher plate velocity; and P_{ao}, the aortic blood pressure. The input to the system is e_m, the motor voltage (refer to **(2)**).

(a) From the eigenvalues obtained, comment on the stability of the system.

(b) If the blood pressure is the measured output, Determine the steady-state error for a unit step input.

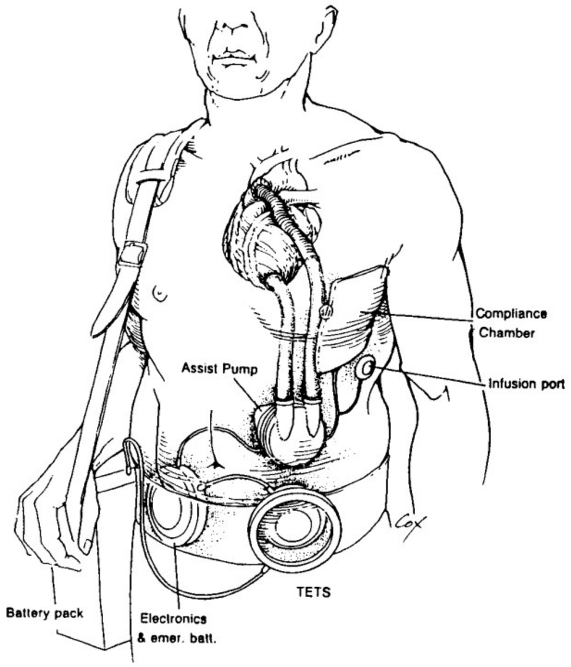

Figure 3: EVAD implemented in parallel with the heart

4. In the past, Type-1 diabetes patients had to inject themselves with insulin three to four times a day. New delayed-action insulin analogues such as insulin Glargine require a single daily dose. A similar procedure to the one described in the Pharmaceutical Drug Absorption case study of this chapter is used to find a model for the concentration-time evolution of plasma for insulin Glargine. For a specific patient, state-space model matrices are given by (refer to **(3)**, **(4)**).

$$\begin{bmatrix} \dot{x_1} \\ \dot{x_2} \\ \dot{x_3} \end{bmatrix} = \begin{bmatrix} -0.435 & 0.209 & 0.02 \\ 0.268 & -0.394 & 0 \\ 0.227 & 0 & -0.02 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} u$$

The state variables are:-
x_1: insulin amount in plasma compartment
x_2: insulin amount in liver compartment
x_3: insulin amount in interstitial (in body tissue) compartment
The system's input is u = external insulin flow and its output y is plasma insulin concentration such that $y = \begin{bmatrix} 0.0003 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix}$

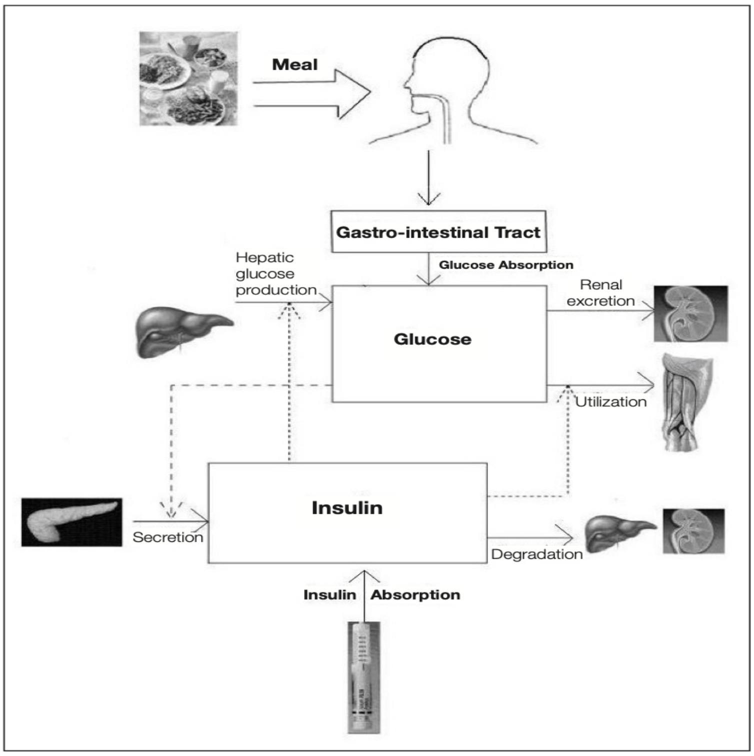

Figure 4: Schematic diagram summarizing the glucose-insulin model

Use the final value theorem to calculate the steady-state error for unit impulse, unit step and unit ramp inputs.

References

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[2] U. Tasch, J. Koontz, M. Ignatoski, and D. Geselowitz, "An adaptive aortic pressure observer for the penn state electric ventricular assist device," *IEEE Transactions on Biomedical Engineering*, vol. 37, no. 4, pp. 374–383, 1990.

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