Tutorial #5
ELL-225: Control Engineering

Session: Semester-II (2022-23)

1. A HelpMate transport robot shown in Fig. (1) is used to deliver goods in a hospital setting. The robot can deliver food, drugs, laboratory materials, and patients' records (*Evans, 1992*)(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) What are the eigenvalues and eigenvectors of the system?

   (c) For finding the zero input response (ZIR) easily, do some similarity transformation and then write down the expression of $x(t)$.

   (d) Choose the initial condition of the states to be equal to an eigenvector. Comment on the ZIR using the same.

   (e) Which eigenvector would you choose as $x(t_0)$ if a faster ZIR is desired?

Figure 1: HelpMate transport robot

2. Arc welding is one of the most important areas of application for industrial robots. In most manufacturing welding situations, uncertainties in the dimensions of the part, the geometry of the joint, and the welding process itself require the use of sensors for maintaining weld quality. Several systems use a vision system to measure the geometry of the puddle of melted metal, as shown in Fig. (2). This system uses a constant rate of feeding the wire to be melted.

   (a) Calculate the range of K for the system that will result in a stable system.

   (b) For half of the maximum value of K found in part (a), determine the roots of the characteristics equation.

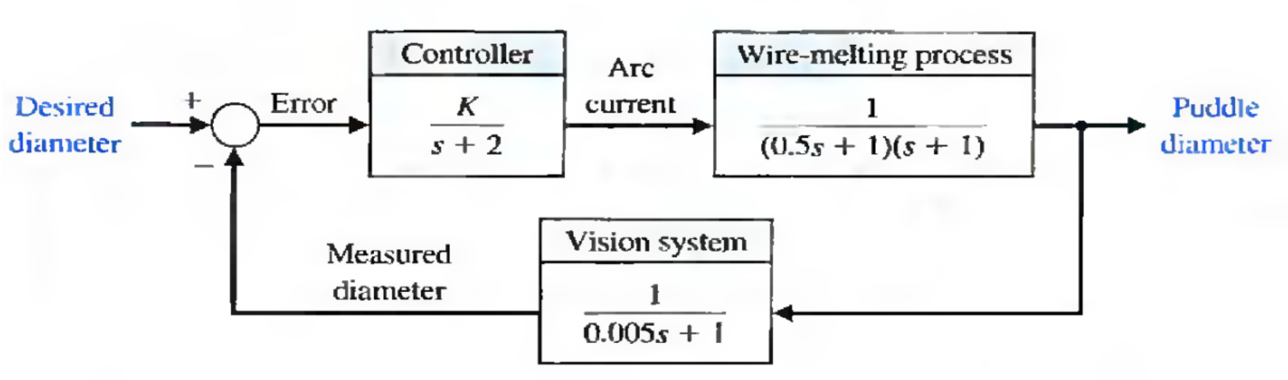

Figure 2: Welder Control

3. An electric ventricular assist device (EVAD) 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 (*Tasch, 1990*)(2).

   (a) Find system eigenvalues and eigenvectors.

   (b) Find an appropriate similarity transformation matrix to diagonalize the system.

   (c) Obtain the state-space system's diagonal representation.

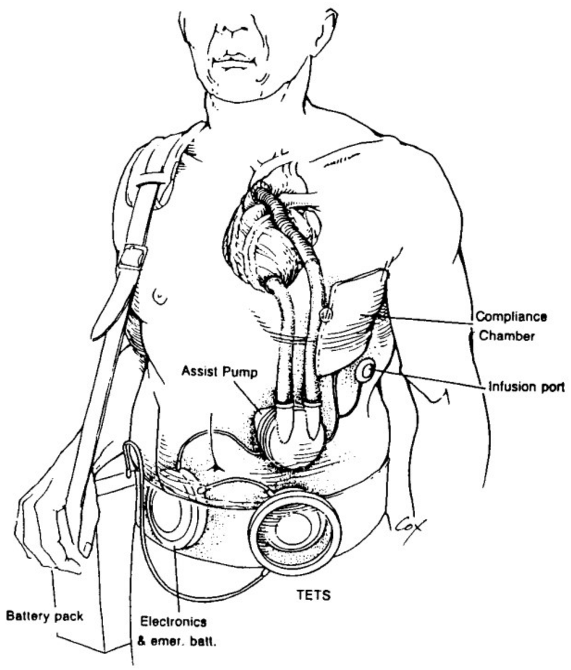

Figure 3: Electric Ventricular Assist Device

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 (*Tarın, 2005*)(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.

(a) Comment on the stability of the system

(b) Find a similarity transformation to diagonalize the system

(c) Obtain the state space representation for the diagonalized system

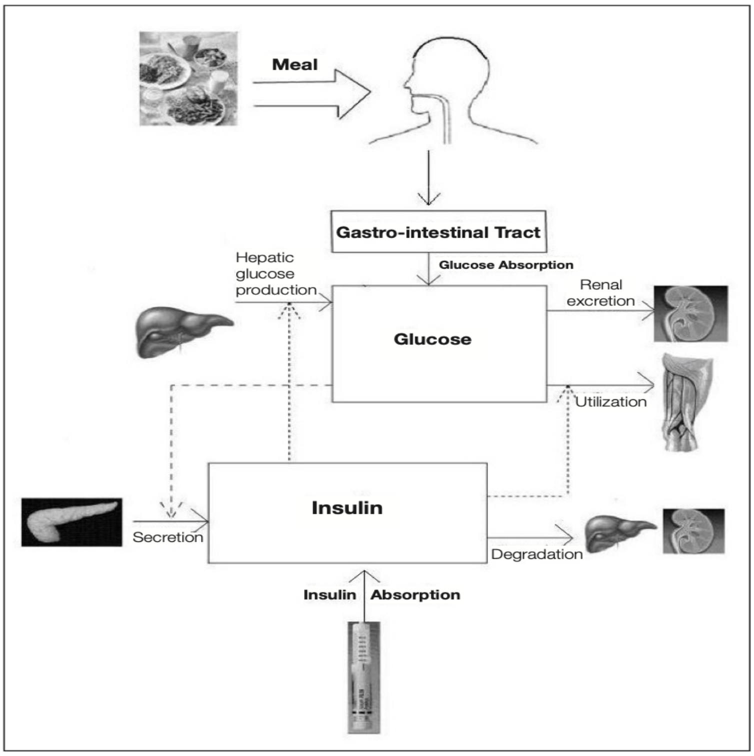

Figure 4: Schematic diagram summarizing the glucose-insulin model

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.

[3] C. Tarin, E. Teufel, J. Pico, J. Bondia, and H.-J. Pfleiderer, “Comprehensive pharmacokinetic model of insulin glargine and other insulin formulations,” *IEEE Transactions on Biomedical Engineering*, vol. 52, no. 12, pp. 1994–2005, 2005.

[4] E. Lehmann, C. Tarín, J. Bondia, E. Teufel, and T. Deutsch, “Incorporating a generic model of subcutaneous insulin absorption into the aida v4 diabetes simulator: 1. a prospective collaborative development plan,” *Journal of diabetes science and technology*, vol. 1, pp. 423–35, 05 2007.