CASE STUDY #5: Applications of control systems: An Artificial Limb

The goal of this week is to evaluate one application of control systems, focusing on the time response and stability characteristics. These concepts will be illustrated by studying the components of an artificial limb. The development of newer and better prostheses is parallel to the advances in electronics, control systems and especially their integration in a biological system. For obvious reasons, there has been a social interest in the development of artificial aids for people with limited limb mobility and usage as well as patients without limbs. Because of the human brain has a natural delay time between the decisions of the brain and the reception of its signals by the muscles. This means that the designers have to fix limits in the capability of an automatic limb. If the prosthesis were to sensitive and fast, it would respond too quickly for the body and brain to control it. If it responds to slow, the natural interaction between body and brain would be lost.

The Figure shows a simplified block diagram for a closed-loop bionic arm. For simplicity we will consider only a unidirectional movement. The brain measures the desired position and the perceived position, producing an error signal that is inputted into the artificial limb. A series of highly sensitive electrodes detect the electrical signals (electromiogram) that are fed into a power amplifier with tachometric feedback that drives a DC motor. The output of the circuit is the velocity of the arm that once integrated results in the position of the limb.
With the following Transfer Functions:

\[ G_B(s) = 1 + \frac{0.1}{s} \]
\[ G_N(s) = \frac{4}{s + 4} \]
\[ G_M(s) = \frac{5}{s^2 + 11s + 10} \]

\( G_B(s) \) represents the action from the brain.
\( G_N(s) \) models the nervous system, where \( \frac{1}{4} \) is the time constant, approximately the neuromuscular delay.
Once the mioelectric signal has been detected, it is amplified with a gain of \( K_B \).
\( G_M(s) \) models the power amplifier, control motor and mechanic load. There are two time constants, that are associated with the mechanical inertia and the motor delay.
\( K_T \) represents a feedback tachometer providing feedback for the motor and the arm.

1.- Find the transfer function for the subsystem made of \( G_M \) and the tachometer

2.- Design \( K_T \) in order to for the previous subsystem to be critically damped

3.- Plot and compare the Time Responses for the previous subsystem in open loop and closed loop by the tachometer. Assume step inputs

4.- What is the result of having the feedback tachometer?

5.- What are the advantages of using the feedback tachometer?

6.- Find the transfer function for all the system. \( X(s) \) is the position of the arm (output) and the desired position is the input to the brain.

7.- Design \( K_B \) to ensure that the bionic arm is stable

8.- Plot the time response for the whole system for 3 cases of \( K_B \) in its range of stability (chose one value in the lower end, one in the middle and the third one in the higher end; you can use more cases if you consider it necessary). Assume step input to the brain.

9.- Plot the time response for a value of \( K_B \) outside the stability range. (Also step input).

10.- What do you think would physically happen in this case?

11.- Create the lab report according to the guidelines, answers to the questions and diagrams.
ELECTRICAL ENGINEERING TECHNOLOGY PROGRAM
EET 433 – CONTROL SYSTEMS ANALYSIS AND DESIGN

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SUMMARY SHEET

To be completed during the laboratory period
Submit it to the instructor at the end of the laboratory period

1.- Design Value for Kt:

2.- Design Value for Kb:

3.- Range of Stability:

Instructor’s Signature and Date: