Tutorial 10
ELL-225: Control Engineering

Session: Semester-II (2022-23)

1. A slave robotic manipulator/hand is a nonlinear system with coupled effects among the joints. For such manipulators, the gear reduction ratio of the gear box at the motors is high. The normal operating velocities and accelerations are limited. Plus, the robotic hand usually grasps or manipulates the object in a limited area, and thus the motion range of each joint is relatively small. These factors allow us to consider the components of the nonlinear and coupling terms of robotic hand dynamics as disturbances and a linear model for each joint is applicable. The idea leads to a decentralized control structure, in which each joint is controlled independently of the others.

   Assume that the transfer function of a joint R_1 is $P(s)$, which includes the DAC gain, the amplifier gain, the motor's electrical-mechanical dynamic relation and the encoder feedback gain. Then $X(s) = P(s)V(s)$ where $V(s)$ is the Laplace transform of $v(t)$, the voltage applied to the D/A channel of the I/O board, and $X(s)$ is the Laplace transform of $x(t)$, the resulting position of joint R_1. In view of a single DC motor control system, the open-loop transfer function for joint R_1 has the form

$$P(s) = \frac{K}{s^2 + as}$$

   where $K = 48500$ and $a = 2.89$ [(1)]. For designing suitable controllers, one may use frequency domain analysis. To that end, carry out the following.

   (a) Draw by hand a Bode plot using asymptotic approximations for magnitude and phase.

   (b) Find the phase margin and gain margin.

2. The system block diagram of a floppy disk drive is shown in control Figure (1). Determine the following:

   (a) Sketch the asymptotic Bode diagram for the transfer function obtained from the system block diagram.

   (b) From the Bode plot, determine the phase crossover frequency, the gain crossover frequency, the gain margin, and the phase margin.

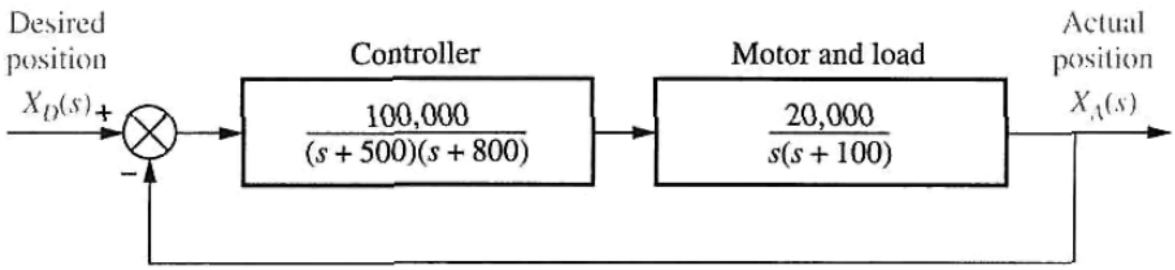

Figure 1: Floppy Disk Drive block diagram

3. Industrial robots, such as that shown in Figure (2), require accurate models for the design of high performance. Many transfer function models for industrial robots assume interconnected rigid bodies with the drive-torque source modeled as a pure gain or first-order system. Since the motions associated with the robot are connected to the drives through flexible linkages rather than rigid linkages, past modeling does not explain the resonances observed. An accurate, small-motion, the linearized model has been developed that takes into consideration the flexible drive. The transfer function

$$G(S) = \frac{999.12(s^2 + 8.94s + 44.7^2)}{(s + 20.7)(s^2 + 34.858s + 60.1^2)}$$

relates the angular velocity of the robot base to electrical current commands [(2)].

   (a) Make a bode plot of the frequency response and identify the resonant frequencies.

   (b) Also, find the gain margin and phase margin of the system.

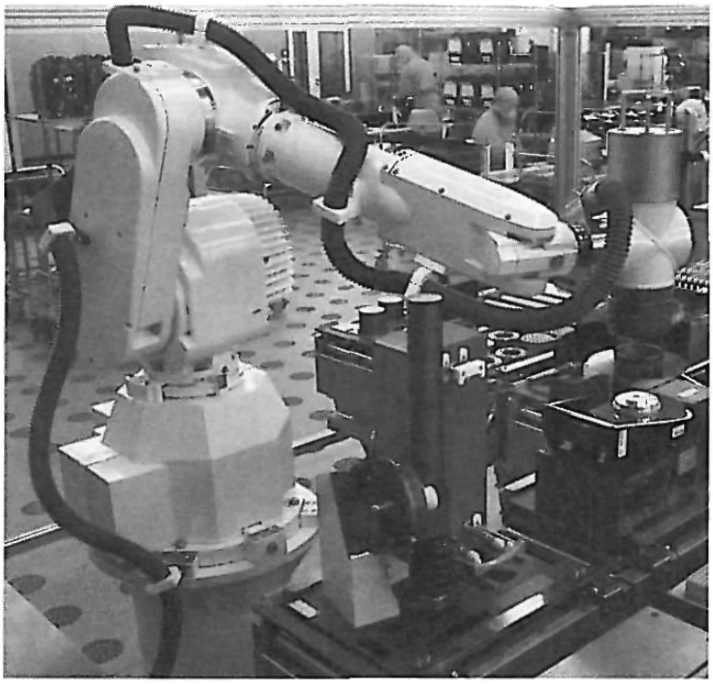

Figure 2: Robot performing construction of computer memory units

4. The charge-coupled device (CCD) that is used in video movie cameras to convert images into electrical signals can be used as part of an automatic focusing system in cameras. Automatic focusing can be implemented by focusing the center of the image on a charge-coupled device array through two lenses. The separation of the two images on the CCD is related to the focus. The camera senses the separation, and a computer drives the lens and focuses the image. The automatic focus system is a position control, where the desired position of the lens is an input selected by pointing the camera at the subject. The output is the actual position of the lens. The camera in Figure 3(b) shows the automatic focusing feature represented as a position control system. Assuming the simplified model shown in Figure 3 (c), draw its bode plot.

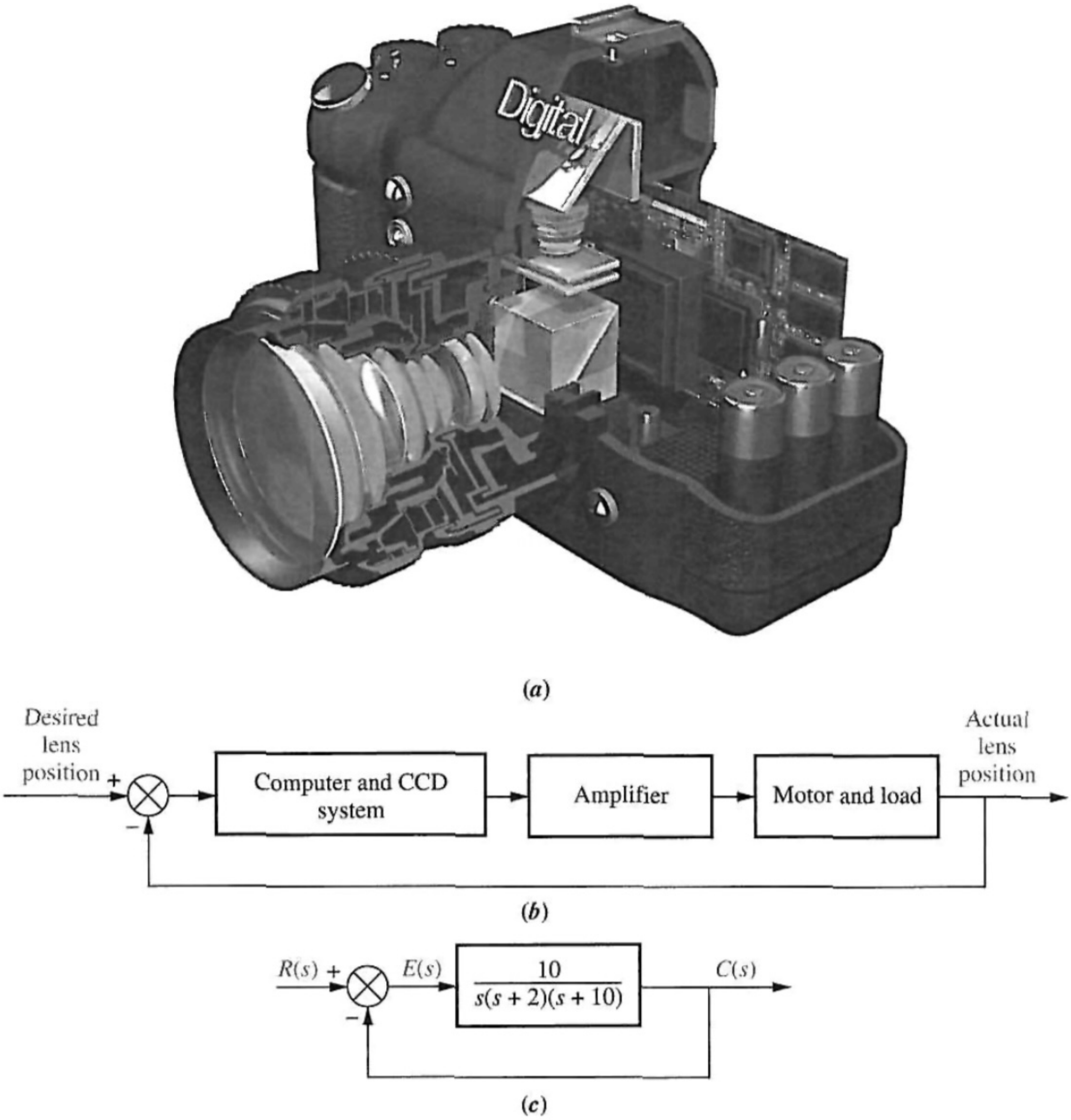

Figure 3: (a) A cutaway view of a digital camera showing parts of the CCD automatic focusing system (b) Functional block diagram (c) Block diagram

References

[1] K. H. Low, H. Wang, K. M. Liew, and Y. Cai, "Modeling and motion control of robotic hand for telemanipulation application," *International Journal of Software Engineering and Knowledge Engineering*, vol. 15, no. 02, pp. 147–152, 2005.

[2] M. Good, L. Sweet, and K. Strobel, "Dynamic models for control system design of integrated robot and drive systems," 1985.