(20 points) 5.4 Consider the system in 5.3(ii) with a required steady-state error of 20%, and an adjustable PI controller zero location. Show that the corresponding closed-loop characteristic equation is given by

$$1+K\left(\frac{s+a}{s}\right)\frac{1}{(s+3)(s+5)}=0$$

Next, rewrite the equation as

$$1+K_f G_f(s)=0$$

where $K_f = K$ is a constant and $G_f(s)$ is a function of s, and examine the effect of shifting the zero on the closed-loop poles.

a) Design the system for a dominant second order pair with a damping ratio of 0.5. What is ω_n for this design?

b) Obtain the time response using a CAD program. How does the time response compare with that of a second order system with the same ω_n and ζ as the dominant pair? Give reasons for the differences.

c) Discuss briefly the tradeoff between error, speed of response and relative stability in this problem.

(20 points) 5.8 Repeat Problem 5.7 with a required settling time less than 0.5 s and an undamped natural frequency of 10 rad/s.

Design a controller for the plant transfer function

$$G(s)=\frac{1}{(s+1)(s+5)}$$

(20 points) 6.5 Design a proportional controller for the system in Problem 6.1(a) to meet the following specifications here possible. <u>If the design specification cannot be met, explain why and suggest a more appropriate controller.</u>

(a) A damping ratio of 0.7.

(b) A steady-state error of 10 % due to a unit step.

(c) A steady-state error of 10 % due to a unit ramp.

(20 points) 6.11 Consider the DC motor position control system of Example 3.6, where the (type 1) analog plant has the transfer function

$$G(s)=\frac{1}{s(s+1)(s+10)}$$

and design a digital controller by using frequency response methods to obtain a settling time of about one second and an overshoot of less than 5%.

(20 points) 7.14 Autonomous underwater vehicle (AUV) are robotic submarines that can be used for a variety of studies of the underwater environment. The vertical and horizontal dynamics of the vehicle must be controlled to remotely operate the AUV. The INFANTE is a research AUV operated by the Instituto Superior Tecnico of Lisbon, Portugal. The variables of interest in horizontal motion are the sway speed and the yaw angle. A linearized model of the horizontal plane motion of the vehicle is given by

$$\begin{bmatrix} \dot{x}1 \\ \dot{x}2 \\ \dot{x}3 \end{bmatrix} = \begin{bmatrix} -0.14 & -0.69 & 0.0 \\ -0.19 & -0.048 & 0.0 \\ 0.0 & 1.0 & 0.0 \end{bmatrix} \begin{bmatrix} x1 \\ x2 \\ x3 \end{bmatrix} + \begin{bmatrix} 0.056 \\ -0.23 \\ 0.0 \end{bmatrix} u$$

$$\begin{bmatrix} y1 \\ y2 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x1 \\ x2 \\ x3 \end{bmatrix}$$

where x_1 is the sway speed, x_2 is the yaw angle, x_3 is the yaw rate and u is the rudder deflection. Obtain the discrete state-space model for the system with a sampling period of 50 ms.

The INFANTE vehicle (Source: from paper by Silvester and Pascoal, “Control of the INFANTE UAV using gain scheduled static output feedback", *Control Engineering Practice*, 12 (2004) 1501-1509).