Capstone: Modern Control Design and Analysis

Modeling, Design, and Performance Evaluation

Please provide a report on the analysis of the given transformation function based on the following questions, accompanied by thorough analysis and simulation using MATLAB:

$$G(s) = \frac{1.8s + 2.67}{s^3 + 9.25s^2 + 28.36s + 28.81}$$

1. Calculate the zeros and poles of the system using MATLAB. Determine whether the open-loop system is stable and minimum phase. Provide a detailed analysis of the system's characteristics.
2. Obtain a state-space representation for the system.
3. Investigate the controllability and observability of the obtained state-space representation. Is it possible to design a state feedback controller and an observer for this representation? If the obtained state-space representation is uncontrollable, separate it into controllable and uncontrollable subsystems. Similarly, if the obtained state-space representation is unobservable, separate it into observable and unobservable subsystems.
4. If the obtained state-space representation is not minimal, obtain a minimal state-space representation for the system.
5. Plot the open-loop system's step response (if stable) for a unit step input and arbitrary initial conditions.
6. Simulate the open-loop system using the obtained state-space representation and a negative unity feedback loop. Plot the closed-loop system's step response and calculate its poles and zeros. Provide a comprehensive analysis of the closed-loop system's characteristics.
7. Design a state feedback controller for the system such that its poles are placed at some desired locations on the left-hand side of the jω-axis. Plot the closed-loop system's step response, state variables, and control signal. Finally, compare the poles and zeros of the closed-loop system with those of the open-loop system. Perform this step for both far and close pole placements and compare the control signal and state feedback gain in both cases.
8. Design a static tracker for the obtained state-space representation.
9. Design an integral (robust) tracker for the obtained state-space representation.

10. Compare and analyze the performance of the two designed tracking controllers based on the following criteria:
    - Tracking performance
    - Robustness in the presence of model parameter variations
    - Closed-loop system performance under constant disturbances.
11. Design a full-order observer for the obtained state-space representation. Determine the criterion for selecting the observer poles. Plot the state variables of the system and the estimation error. Choose two sets of slow and fast observer poles and design the corresponding full-order observers. Plot and compare the state variables of the original system and the estimated ones using both observers.
12. Change one of the system parameters and use the same observer designed in the previous step to estimate the states of the modified system. Analyze the results.
13. Design a reduced-order observer for the obtained state-space representation. Plot the state variables of the system and the estimation error.
14. Design a state feedback controller for the closed-loop system using the estimated states such that the poles are located on the left half of the jω-axis and the step response exhibits acceptable overshoot and settling time behavior. Plot the step response and the state variables of the system. Assume that the actual states are not available and only the estimated states can be used for state feedback. Consider a full-order observer for this question.
15. Design a state feedback regulator with a reduced-order observer for the assumed system.
16. Design a state feedback tracker with a full-order observer for the assumed system.
17. Design a state feedback tracker with a reduced-order observer for the assumed system.
18. Obtain the optimal state feedback gain for the system to minimize the cost function below for different R and Q matrix values:

$$J = \int (x^T Q x + u^T R u)\, dt$$

    To evaluate the impact of changing Q and R on the system's performance, consider a fixed Q matrix and manipulate the R matrix by changing its values. Then, repeat the process with R as a fixed matrix and Q as the variable matrix. Compare the simulation results obtained from both scenarios and provide insights into the sensitivity of the system to variations in the Q and R matrices. This analysis can be used to optimize the system's behavior and improve its performance.