SERVO MOTOR CONTROL DESIGN TASK

Due Date **Tuesday** week 13. Worth 20%.

In this task, you will connect material covered in lectures, tutorials and practicals. Content needed for this task includes the topics in lecture of Motors and Operational Amplifiers, Analytic Time Response lecture, Reduction of Subsystems, Stability and Steady State Error, and their related tutorials and practicals.

You will develop fundamental skills in control system design and synthesis by implementing your first control system. Specifically, you will implement a custom-built motor control system.

1 Background: Servo motors are everywhere.

Please re-read the background section of the Servo Motor System Identification task sheet.

2 Assessed Questions – Control System Design

In this section, you will perform a control system design study on the unknown system that you performed system identification in Question 3 of the EGB345 Servo Motor System Identification task.

You will need the K_m and α values you estimated as part of that Question 3 task of the EGB345 Servo Motor System Identification task.

You have the option to complete the following activities in **either** MATLAB or Simulink. Using a mixture of MATLAB and Simulink is also allowed. Please use the tool you think is easiest for you to complete the design task.

2.1 Question 1: Initial closed loop

Build a MATLAB or Simulink representation of the servo motor in open loop with the parameters you estimated in Question 3 of the EGB345 Servo Motor System Identification task. We call this representation *your open-loop system* in the following tasks.

1. Analytically create the transfer function expression of a unit negative feedback closed-loop system containing a gain controller K=1 in front of your open-loop system. Analytically determine the settling time and % overshoot (if any).
2. Build an appropriate MATLAB or Simulink representation of the closed-loop system.
3. Plot the step response of the closed-loop system. Comment on whether it matches your analytically determined transfer function.

Submit: all your MATLAB scripts or your Simulink model used in this question (In a zip file).
Also submit the following: (in the provided report template).

1. The derived transfer function expression of the closed-loop system with K=1. Include your working.
2. Calculated settling time and % overshoot, if any.
3. Plot of the step response of the closed-loop system and submit as ‘png’ or ‘jpg’ files.
4. Comment on whether the plot matches your analytic results.

2.2 Question 2: Design control for requested response

You are asked to design a controller to achieve 5% overshoot. Complete the following tasks:

1. Analytically create the transfer function expression of a unit negative feedback closed-loop system containing a general gain K controller in front of your open-loop system.
2. Determine a value of K that results in 5% overshoot. Report the location of the closed-loop poles that would result.
3. Then build an appropriate MATLAB or Simulink representation of the closed-loop system with the designed value of K. Plot the step response of the closed-loop system. Comment on whether it matches your analytic results.

Submit: all your MATLAB scripts or your Simulink model used in this question (In a zip file).
Also submit the following: (in the provided report template).

1. The derived transfer function for a gain of K. Include your working.
2. The determined K and the closed-loop poles.
3. Plot of the step response of the closed-loop system and submit as ‘png’ or ‘jpg’ files.
4. Comment on whether the plot matches your analytic results.

2.3 Question 3: Investigation of the gain K

You are asked to evaluate the impact of errors in the value of K, such as what might arise due to imperfect hardware components.

Complete the following tasks:

1. Analytically determine the location of the closed-loop poles for 5 values of K below and 5 values above the value you designed in Question 2. We suggest increasing and decreasing factor of 10% (that is 0.9*K, 0.8*K, … and 1.1*K etc.).
2. Neatly hand draw a graph in the s-plane that reports the 10 closed-loop pole locations (on paper). Neatly label a couple of the poles with their corresponding K-value. Comment on the meaning of what you see in the graph you have drawn.
3. Using your MATLAB or Simulink representation of the closed-loop system, simulate the step response of these 10 cases.

Submit: all your MATLAB scripts or your Simulink model used in this question (In a zip file).
Also submit the following: (in the provided report template).

1. Report in a table, which has a new row for each of your ten K values next to the corresponding closed-loop pole location, the plot of the step response of the closed-loop system as a ‘png’ or ‘jpg’ file.
2. Your drawing of the closed-loop pole location, and your comment about meaning of what you see you have drawn.

2.4 Question 4: Improved transient response using a dynamic compensator

You may complete this task last (after Questions 5, 6 and 7) if you want. That is, you may initially skip this task and proceed to Question 5 if you want.

You are asked to introduce dynamic compensation so closed-loop system has half the settling time achieved in Question 2 but keeping the same steady state properties. (Dynamic compensation is the same as a dynamic controller and means a controller with poles and/or zeros). You may use other compensators, but one useful compensator is a lead compensator which has the transfer function with one zero z_c and one pole p_c (with $z_c < p_c$)

$$\frac{s + z_c}{s + p_c}$$

Complete the following tasks:
1. Analytically determine the location of the desired closed-loop poles to achieve the requested response.
2. Using an s-domain graph, determine the location of your compensator's poles and zero location that allow you to achieve the requested response.
3. Determine the value of K that achieves the requested response (with the step 2 poles and zeros).
4. Using your MATLAB or Simulink representation of the closed-loop system, make modifications to include the designed compensator (designed in the above steps 2 & 3), and simulate its step response. Comment of the meaning of what you see.

<u>Submit</u>: all your MATLAB scripts or your Simulink model used in this question (In a zip file).
<u>Also submit the following:</u> (in the provided report template).
1. Your determined desired closed-loop pole location. Include your working.
2. Your desired compensator (poles, zero and gain value). Include your working.
3. Plot of the step response of the closed-loop system and submit as 'png' or 'jpg' files.
4. Comment on whether the plot matches what you excepted given your answer to task 2 of this question.

2.5 Question 5: Robustness study – model parameter error

You may complete this task on the basis of simple gain K controller in unit negative closed-loop feedback (you don't need to use your answer to Question 4).

In a control system engineering context, the word "robustness" has a particular technical meaning. A control system design is robust if it is able to handle uncertainty (such as uncertainty in model parameters). In the following we examine uncertainty in the sense of some lack of knowledge of the parameters of the servo motor transfer function.

Recall that <u>your open-loop system</u> estimated from measurement data from the system and hence your estimated model is only an approximate representation of the true system. Let us assume that your estimated parameters are within 10% of the true value. That is, the true value of the K_m parameter is between $0.9K_m$ and $1.1K_m$ and true value of the α parameter is between 0.9α and 1.1α, where K_m and α values you estimated as part of that Question 3 task of the EGB345 Servo Motor System Identification task. **You don't know the specific K_m and α values but are asked to design a single simple gain compensator K that works o.k. for all the possibility K_m and α values in the specified ranges.**

Consider a simple gain compensator K, and complete the following tasks:
1. Analytically determine a value of K that ensures the % overshoot is no worse than the specified in Question 2, given the true K_m parameter might be any value between $0.9K_m$ and $1.1K_m$ and the true α parameter might be any value between 0.9α and 1.1α. *The phrase "no worse than the specified in Question 2" means the closed-loop system response with your designed value of K can have less overshoot than 5%, but none of the possible closed-loop systems with your designed value of K (possible systems corresponding to the possible values of K_m and α) should have overshoot great than 5%.*

2. Provide an argument to justify why your design is robust to the described uncertain in K_m and α values.
3. Using your MATLAB or Simulink model of the closed-loop system (with your designed value of K in task 1 of this question) when the true values are $0.9K_m$and 0.9α to simulate its step response.
4. Using your MATLAB or Simulink model of the closed-loop system (with your designed value of K in task 1 of this question) when the true values are $1.1K_m$and 1.1α to simulate its step response.
5. Comment on what you observe from the perspective of robustness, which system exhibits highest overshoot. Explain using analysis of the impact of the parameter values.

Submit: your MATLAB or Simulink representation used in this question.
Submit the following (in the provided report template).

1. Your analysis and process for finding your robust K. (less than 2 pages).
2. Your argument of why it is robust (less than 1 page).
3. Plot of the step response of the first (smaller parameter values) closed-loop system and submit as 'png' or 'jpg' files.
4. Plot of the step response of the second (larger parameter values) closed-loop system and submit as 'png' or 'jpg' files.
5. Comment, discussion and explanation (less than 1 page).

2.6 Question 6: Robustness study 2 - measurement error

You may complete this task on the basis of simple gain K controller in unit negative closed-loop feedback (you don't need to use your answer to Question 4).

In this question, you are investigating the impact of (random) measurement uncertainties (that is, some lack of knowledge about the feedback path gain). You are told that the measurement process used to determine the feedback signal potentially has a 10% scaling uncertainty. Hint: in MATLAB this can be represented as feedback gain element of *H* with *H* have a value between 0.9 and 1.1. **You don't know the specific H value so must design to allow the possibility H has any of the possible values.**

Modify your MATLAB or Simulink model of the closed-loop system to include described measurement error effect.

Note: % overshoot is defined in terms of the final steady state value reached by the response (the final steady state value can be different than 1).

Then complete the following tasks:

1. Analytically determine a value of K that ensures the % overshoot is no worse than the specified in Question 2, given the feedback gain element of H might have any value between 0.9 and 1.1.
2. Provide an argument to justify why your design is robust.
3. Using your MATLAB or Simulink representation of the closed-loop system (with your designed value of K in task 1 of this question) to determine the step response when H is fixed and equal to its smallest possible values (when H=0.9).
4. Using your MATLAB or Simulink representation of the closed-loop system (with your designed value of K in task 1 of this question) to determine the step response when H is fixed and equal to its largest possible values (when H=1.1).
5. Comment on what you observe from the perspective of robustness. Explain using analysis of the impact of measurement error.

Submit: your MATLAB or Simulink representation used in this question.

Submit the following (in the provided report template).

1. Your analysis and process for finding your robust K (less than 2 pages).
2. Your argument of why it is robust (less than 1 page).
3. Plot of the step response of the closed-loop system with H=0.9 and submit as 'png' or 'jpg' files.
4. Plot of the step response of the second (large parameter value) closed-loop system with H=1.1 and submit as 'png' or 'jpg' files.
5. Your comment, discussion of observed robustness. Your analytic explanation (less than 1 page).

2.7 Question 7: Robustness study 3 - an unmodelled pole

You may complete this task on the basis of simple gain K controller in unit negative closed-loop feedback (you don't need to use your answer to Question 4).

In this question, you are investigating the impact of an unmodelled fast pole. You are told the true system has an additional fast pole at β and is described by:

$$G_o(s) = \frac{V_p(s)}{V_m(s)} = \frac{K_m}{s(s+\alpha)(s+\beta)}$$

You are told the unmodelled pole is 10 times faster than α, in the sense that $\beta = 10\alpha$ ("unmodelled" means you didn't know the pole was present, and don't know its specific value). **You don't know the specific value of β but will examine the impact of a number of possible values.**

Modify your MATLAB or Simulink model of the closed-loop system to include described measurement error effect and having the gain you designed in Question 2.

Then complete the following tasks:

1. Analytically create the transfer function expression of a unit negative feedback closed-loop system containing a gain controller having the value of K you designed in Question 2 and the new $G_o(s)$ given above.
   a. If $\beta = 10\alpha$ (i.e. faster). What are the closed-loop pole locations? Analytically estimate settling time and % overshoot
   b. If $\beta = 2\alpha$ (i.e. not so fast). What are the closed-loop pole locations? Analytically estimate settling time and % overshoot, if possible.
2. Modify your MATLAB or Simulink representation of the new closed-loop system to determine the step response, when:
   a. $\beta = 10\alpha$
   b. $\beta = 2\alpha$
3. Comment on what you observe in the impact of the additional pole.

Submit: your MATLAB or Simulink representation used in this question.
Submit the following (in the provided report template).

1. Your analysis plus your settling time and overshoot answers (less than 2 pages).
2. Plot of the both step responses of the new closed-loop system.
3. Your comment, discussion of impact of additional pole (less than 1 page).

3 Submission aspects

This multiple part assessment submission is very short, but each of the assessment submission parts must be scannable by SafeAssign and 10MB or less (attempts to subvert SafeAssign will be considered academic misconduct). Data and text must be ascii and editable.

3.1 Submission part i) [Document]

You must use the provided word document template: Includes text and plots. Replace highlighted text with your submissions. Submit the word document.

Must be unzipped word or pdf document.

3.2 Submission part ii) [File attached submissions, 7 zip files]

For each of the 7 questions submit a separate zip file of the MATLAB and/or Simulink used in that question.