



Bridging the expert knowledge gap with LLM's

Friday Seminar



Agenda

- My research trip to Aalborg
- Intro to joint research with Julia on LLM's in our teaching
- Can a non-STEM user solve our exam with Chat-GPT?

Aalborg, Denmark



RESEARCH GROUP

AUTOMATION & CONTROL



The section works within the decision mechanism shaping the future in the desired way. Physical information is converted into digital data and processed by an algorithm. The result is information on how to influence the environment and control may hence be seen as a "machine brain".

Rafal Wisniewski

Civilingeniør, Ph.D. EE, Ph.D. Math
Professor, Department of Electronic Systems
Professor, The Technical Faculty of IT and Design
Professor, Automation & Control
Learning and Decisions Lab
Machine Learning
Aalborg University Space Center

Water Lab



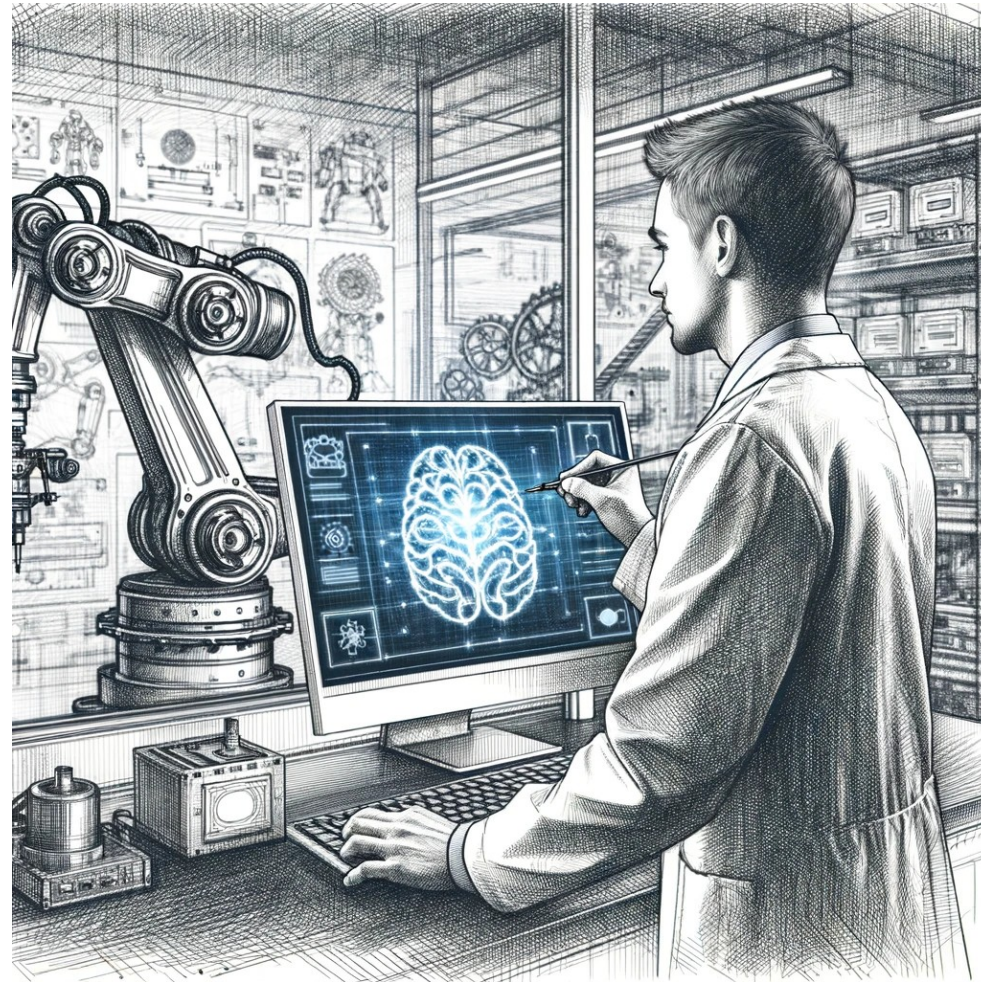
The LLM-powered control-engineer

Safety?

Skillsets?

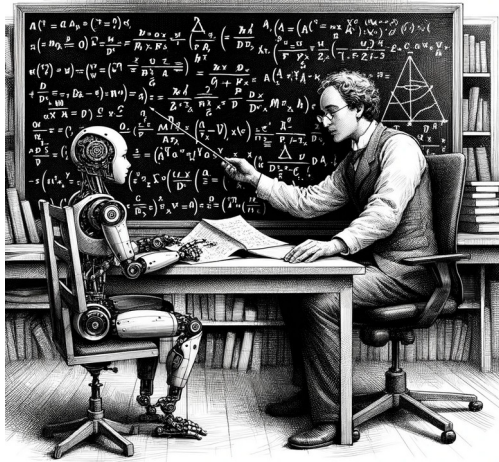
Workflow?

Teaching?



Bridging the expert knowledge gap with LLM's

Typical studies:



Our proposed study:



- "Can Chat-GPT solve an exam?"

**Capabilities of Large Language Models in Control Engineering:
A Benchmark Study on GPT-4, Claude 3 Opus, and Gemini 1.0 Ultra**

Darioush Kevian¹, Usman Syed¹, Xingang Guo¹, Aaron Havens¹,
Geir Dullerud¹, Peter Seiler², Lianhui Qin^{3,4}, and Bin Hu^{*1}

¹University of Illinois Urbana-Champaign

²University of Michigan

³Allen Institute for AI

⁴University of California San Diego

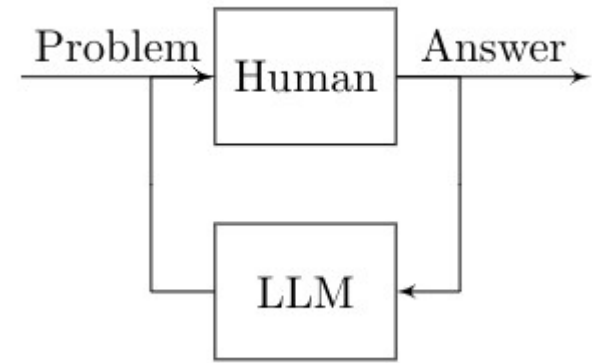
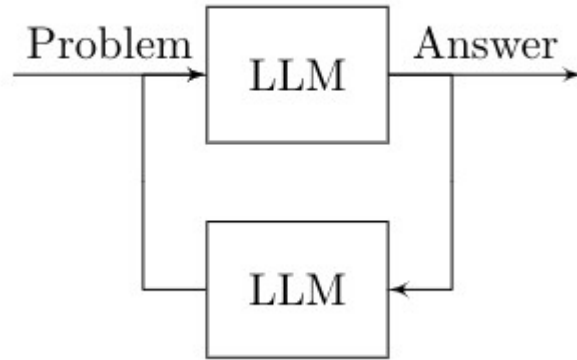
* Corresponding author. E-Mail: binhu7@illinois.edu

- "Can a student with LLM-support solve an exam?"
- Human operators in closed-loop with an LLM
- Students have engineering background (but not control)
- Experiment planned for August

Abstract

In this paper, we explore the capabilities of state-of-the-art large language models (LLMs) such as

Problem-solving with LLM's



Can a non-STEM-user solve our exam?

- Ruth Horak (thank you)
- Copenhagen University
- Works with generative AI at the university
- Has LLM-experience, but not STEM background
- Using Chat-GPT (GPT-4, with image reading and python interface)
- Solved Jan 13 2021 exam in English

Question 2

2. The number of rabbits $x_1(t)$ and foxes $x_2(t)$ in a forest can be described by the Lotka-Volterra equations

$$\begin{aligned}\dot{x}_1 &= \alpha x_1 - \beta x_1 x_2 \\ \dot{x}_2 &= \delta x_1 x_2 - \gamma x_2 - u,\end{aligned}$$

where control signal u is the number of foxes killed during a week during the fox hunting, and α , β , γ and δ are positive real constants.

- Determine all stationary points (x_1^0, x_2^0, u^0) for the system when $u^0 = 0$. (1 p)
- Linearize the system around the stationary point where $x_1^0 > 0$ and $x_2^0 > 0$. Assume that the measurement signal is the number of foxes, i.e., $y = x_2$. (2 p)
- Is the linearized system asymptotically stable, stable, or unstable? (1 p)
- The number of foxes $y = x_2$ is at one occasion higher than the desired setpoint r . We want to determine the number of foxes that should be shot per week as a function of the actual populations of foxes and rabbits, and the actual setpoint. We use the control law $u(t) = l_r r - l_1 x_1 - l_2 x_2$, where l_1 , l_2 and l_r are constant coefficients. Determine l_1 and l_2 so that the closed linear system $Y(s) = G(s)R(s)$ get both poles in $s = -0.2$. (2 p)
- To hunt foxes without hunting rabbits is perhaps not a good idea. Suppose that we, for a constant setpoint $r(t) = \varepsilon\alpha/\beta$, with $0 < \varepsilon < 1$, manage to choose $u(t)$ so that the control error becomes constant and zero, i.e., $x_2(t) = r(t) = \varepsilon\alpha/\beta$, while $x_1(t) > 0$. What will then happen with the number of rabbits $x_1(t)$ when $t \rightarrow \infty$ according to the nonlinear Lotka-Volterra equations? (0.5 p)

Hunting Rabbits and Foxes

- A-C: linearize and analyze stability
- D: Design feedback gains (hunting policy) to place closed-loop poles
- E: Why could it be bad to hunt only foxes? (unstable rabbits)

A-C: Linearize and analyze stability

Anonymous

Thank you. Let's proceed to question 2.b. My formatting is bad, so please start by formatting the question correctly before proceeding to solve the question:

Linearize the system around the stationary point where x

0

$1 > 0$ and x

0

$2 > 0$.

Assume that the measurement signal is the number of foxes, i.e., $y = x2$.

Reasonable prompting

Remember: Format first, solve afterwards. Go step by step when solving the question.

Step 3: Combine the results to find the stationary points.

From the analysis, we have the following stationary points when $u_0 = 0$:

1. When $x_1 = 0$, the first equation is satisfied for any x_2 , but the second equation shows that for x_2 to not be zero, x_1 must be $\frac{\gamma}{\delta}$. This is a contradiction, so we focus on the meaningful solutions.
2. $x_2 = 0$ and x_1 can be any value, but looking at the biological context, $x_1 = 0$ is the only meaningful solution that satisfies both equations simultaneously without considering the non-zero solutions derived from the equations.
3. $x_2 = \frac{\alpha}{\beta}$ and $x_1 = \frac{\gamma}{\delta}$ is a solution that satisfies both equations without contradiction and represents a coexistence equilibrium where both species have non-zero populations.

Conclusion:

Correct equilibria

The stationary points for the system when $u_0 = 0$ are:

- $(0, 0, 0)$: Both species are extinct.
- $(\frac{\gamma}{\delta}, \frac{\alpha}{\beta}, 0)$: A coexistence point where both species have non-zero populations that depend on the values of α , β , γ , and δ .

These points represent the conditions under which the populations of rabbits and foxes do not change, indicating equilibrium states of the system under the condition that no foxes are being removed by hunting ($u_0 = 0$).

Recap of the Linearized System

From 2.b (not explicitly solved here but based on standard procedure), the Jacobian matrix J of the Lotka-Volterra system at the stationary point (x_{01}, x_{02}) is:

$$J = \begin{bmatrix} \frac{\partial \dot{x}_1}{\partial x_1} & \frac{\partial \dot{x}_1}{\partial x_2} \\ \frac{\partial \dot{x}_2}{\partial x_1} & \frac{\partial \dot{x}_2}{\partial x_2} \end{bmatrix} = \begin{bmatrix} \alpha - \beta x_{02} & -\beta x_{01} \\ \delta x_{02} & \delta x_{01} - \gamma \end{bmatrix}$$

Given the stationary point for coexistence is $(x_{01} = \frac{\gamma}{\delta}, x_{02} = \frac{\alpha}{\beta})$, substituting these values into J gives:

$$J = \begin{bmatrix} 0 & -\beta \frac{\gamma}{\delta} \\ \delta \frac{\alpha}{\beta} & 0 \end{bmatrix}$$

Correct linearization

Stability Analysis

To determine the stability of the linearized system, we need to examine the eigenvalues of the Jacobian matrix J . The eigenvalues λ are found by solving the characteristic equation $\det(J - \lambda I) = 0$, where I is the identity matrix.

$$\det \begin{pmatrix} -\lambda & -\beta \frac{\gamma}{\delta} \\ \delta \frac{\alpha}{\beta} & -\lambda \end{pmatrix} = 0$$

$$\Rightarrow \lambda^2 - \left(-\beta \frac{\gamma}{\delta} \cdot \delta \frac{\alpha}{\beta}\right) = 0$$

$$\Rightarrow \lambda^2 + \alpha\gamma = 0$$

This is a quadratic equation in λ , and its solutions are:

$$\lambda = \pm \sqrt{-\alpha\gamma}$$

Since α and γ are positive constants, $-\alpha\gamma$ is negative, making the square root imaginary. Therefore, the eigenvalues are purely imaginary, with no real part:

$$\lambda_{1,2} = \pm i\sqrt{\alpha\gamma}$$

Correct stability analysis

Conclusion on Stability

The linearized system has eigenvalues with zero real parts and non-zero imaginary parts. This indicates that the system does not return to the equilibrium point after a disturbance (not asymptotically stable) but also does not diverge from it (not unstable in the sense of growing without bounds). Such a system exhibits **neutral stability** or **marginal stability**, characterized by oscillations around the equilibrium point without damping or growing amplitude.

D: Design feedback gains (hunting policy)

Step-by-step solution guide

Reasonable prompt



Anonymous

Now we are proceeding to question 2.d. As always: Please start by formatting the question correctly. Go then on to solve the question. Check the context with previous questions and go step by step when solving the question.

Stop, wait. Here is question 2.d

The number of foxes $y = x_2$ is at one occasion higher than the desired setpoint r . We want to determine the number of foxes that should be shot per week as a function of the actual populations of foxes and rabbits, and the actual setpoint. We use the control law $u(t) = l_{rr} - l_1 x_1 - l_2 x_2$, where l_1 , l_2 and l_r are constant coefficients. Determine l_1 and l_2 so that the closed linear system $Y(s) = G(s)R(s)$ get both poles in $s = -0.2$.

Fails to actually compute answer

Ruth misinterprets this as a real answer

depend on l_1 and l_2 through how they modify the system's feedback loops.

- l_1 and l_2 effectively adjust the feedback from the rabbit and fox populations, respectively, altering the system's natural frequencies and damping ratios.

Step 5: Matching the Characteristic Equation

To match the desired characteristic equation, you would typically equate the coefficients from the linearized system's characteristic equation (including the effects of l_1 and l_2) to those of the desired equation $s^2 + 0.4s + 0.04$. This process involves:

1. Calculating the Jacobian matrix of the modified system including l_1 and l_2 .
2. Deriving the characteristic equation from this Jacobian.
3. Setting the coefficients of this equation equal to those of the desired characteristic equation.

Conclusion:

Without the explicit forms of the linearized system matrices before and after applying the control law, we cannot directly calculate l_1 and l_2 . However, the process involves adjusting l_1 and l_2 so that the feedback effects they introduce modify the system's dynamics to achieve the desired characteristic equation, thereby placing the poles at $s = -0.2$.

In practical terms, this would likely involve setting up equations based on the linearized system's dynamics that relate l_1 and l_2 to the system's natural frequencies and damping ratios, then solving these equations to match the desired pole locations. This approach underscores the importance of feedback control in shaping the dynamics of a system to meet specific performance criteria, such as stability and response time.



Anonymous

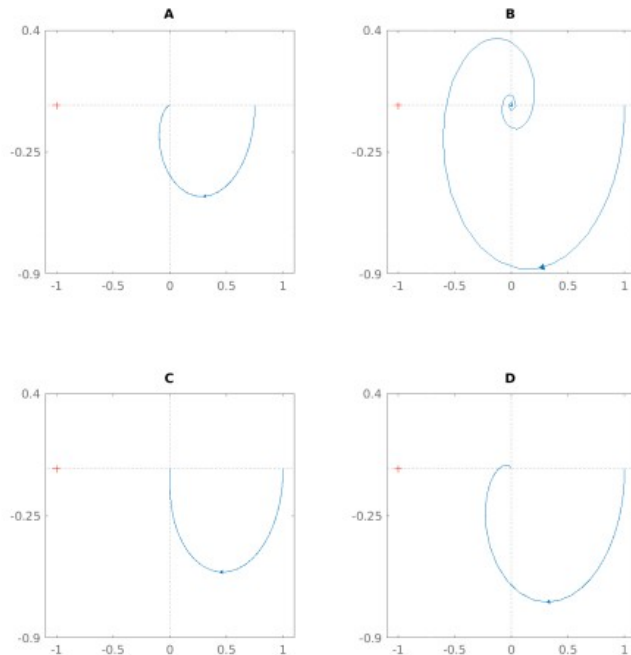
Thank you. Now we are going to proceed to question 2.e. As always - format first, solve afterwards. Explain your thoughts step by step and make sure there is no context from the previous questions you have overlooked. Here is the question:

Question 3

3. In this problem, the following transfer functions are studied:

$$G_1(s) = \frac{4}{(s+2)^2(s+1)} \quad G_2(s) = \frac{4}{(s+2)^2} e^{-s}$$
$$G_3(s) = \frac{3}{(s+2)^2} \quad G_4(s) = \frac{s+4}{(s+2)^2}$$

- a. Figure 1 shows four Nyquist plots. Pair each blot with the corresponding transfer function. Motivate your answer. (2 p)
- b. Suppose that the systems are controlled with a P controller with gain $K > 0$. For every transfer function, determine the values of K that result in stable closed-loop systems. Motivate your answers. (2 p)

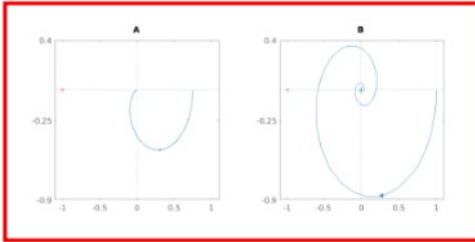


Match Plots and TF's

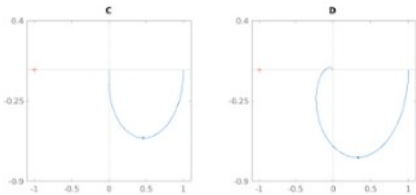
- A: Match TF's with Nyquist plots
- B: Find maximum stable P-controller-gain (gain margin)

A: Match plots

You



Ruth gets plots into the system



Figur 1: Nyquist plots for problem 3.

Only B (delay) is correct.

- $G_1(s) = \frac{4}{(s+2)^2(s+1)}$: This function likely corresponds to Plot A due to the phase lag associated with its poles.
- $G_2(s) = \frac{4}{(s+2)^2} e^{-s}$: Plot B should correspond to this function due to the presence of a time delay, which is evident from the stretched loop.
- $G_3(s) = \frac{3}{(s+2)^2}$: Plot C is likely the match because of the simpler nature of the system (a second-order system without additional poles or zeros).
- $G_4(s) = \frac{s+4}{(s+2)}$: Plot D is the best fit for this transfer function because the presence of a zero in addition to a pole typically results in a clockwise encirclement of the origin.

To summarize, the matching would be:

- Plot A with G_1
- Plot B with G_2
- Plot C with G_3
- Plot D with G_4

The rationale for each match is based on how the number and location of poles and zeros within the transfer functions affect the shape and direction of the corresponding Nyquist plots.

Can you read this format?

Data Analyst

Yes, I can analyze the image of Nyquist plots you've provided. Let's go through each Nyquist plot and pair it with the correct transfer function:

Plot A:

- Does not encircle the origin.
- Reflects a system with poles but no zeros on the right half-plane.
- Resembles a standard second-order system response with a phase lag due to the poles.

Plot B:

- Encircles the origin once counterclockwise, which implies a net negative phase contribution.
- The loop away from the origin suggests the influence of a time delay, as it introduces additional phase lag.
- This behavior is typical of a transfer function with a time delay.

Chat-GPT identifies delay

You

Thank you. Let's proceed to question 3.b. Remember the four transfer functions - please repeat them

Ruth can't check the answers together with the plots

B: Find gain margin

You

3.b. Suppose that the systems are controlled with a P controller with gain $K > 0$. For every transfer function, determine the values of K that result in stable closed-loop systems. Motivate your answers. Go step by step (chain of thought).

Prompts to ensure motivations

Data Analyst

To determine the values of K that result in stable closed-loop systems for each transfer function when controlled with a P controller, we can use the characteristic equation approach. A P controller has a transfer function $C(s) = K$, where K is the gain. The closed-loop transfer function $T(s)$ for a system with open-loop transfer function $G(s)$ and controller $C(s)$ is given by:

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

Thus, the characteristic equation for the closed-loop system is:

$$1 + C(s)G(s) = 0$$

Now, we will apply this to each transfer function:

1. For $G_1(s)$:

$$1 + K \left(\frac{4}{(s-2)^2(s+1)} \right) = 0$$

Solving for K we need to ensure that all the roots of the characteristic equation are in the left half of the s -plane (have negative real parts) for stability.

1. For $G_2(s)$:

$$1 + K \left(\frac{4}{(s-2)^2} \right) = 0$$

Incomplete / incorrect formulation

Moves on before providing answer

Final answer is more of a "recipe" for a solution

To complete this analysis, one could plot the root locus for each $G(s)$ or apply the Routh-Hurwitz stability criterion to the characteristic equation for each case, which provides the conditions that the coefficients of the characteristic polynomial must satisfy for stability.



You

Is there anything more to say? Anything else to add?

Ruth seems to suspect there is more to the question.



Data Analyst

In addition to what's been described, we should remember that the stability of a closed-loop system with a P controller also depends on the system's ability to handle the gain without leading to excessive overshoot or oscillations. Each transfer function's individual characteristics, such as the location and multiplicity of poles and zeros, will influence how the gain K affects stability.

For more detailed stability analysis, the following could be considered:

- **Nyquist Criterion:** The Nyquist path could be plotted for each $C(s)G(s)$, and the number of encirclements around the $-1 + 0j$ point could determine stability.
- **Routh-Hurwitz Criterion:** This method can be applied to find the range of K values that make the system stable without having to plot anything.
- **Bode Plot:** Examining the gain and phase margins can provide insight into how close the system is to instability.

For the exact stability criteria, you would typically substitute K into the characteristic equation and ensure that all roots lie in the left half-plane for continuous-time systems, which might require

The "correct" method is provided, but not used

Question 4

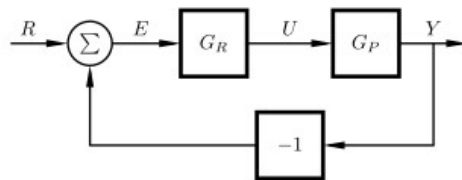
4. You are employed as a consultant at the company Energi AB that works with temperature control of offices. They have found a model that describes heating of a room that is given by the following transfer function

$$G_P(s) = \frac{1}{(1 + 2s)(1 + 3s)}$$

~~a. If you compare this process with the tank labs, does it have dynamics similar to the upper or the lower tank? Motivate your answer! (0.5 p)~~

- b. Today, the company uses a PI controller to control the system. Determine the transfer function $G(s)$ from setpoint R to measurement signal Y for the closed-loop system (see Figure 2). Insert the expressions for G_P and G_R and ensure you get a nice expression for the transfer function (the dominator should be on the form $(s^n + a_1s^{n-1} + \dots + a_{n-1}s + a_n)$). The transfer function for a PI controller is: $G_R(s) = K(1 + \frac{1}{sT_i})$. (2 p)

- c. Given that $T_i = 1$, which is the largest gain K that we can have in the controller and still have an asymptotically stable closed-loop system? (1 p)



Figur 2: Closed-loop system.

Design PI-control for building

- B: Calculate closed-loop TF
- C: Find maximum P-gain for stability
- D: Argue about the choice of controller

- d. Is there another type of controller that you would recommend the company to use instead of a PI controller? Why/why not? (0.5 p)

B: Calculate closed-loop

Data Analyst

Given the system's transfer function $G_P(s)$ and the PI controller's transfer function $G_R(s)$, the objective is to find the transfer function from the setpoint R to the measurement signal Y for the closed-loop system depicted in Figure 2.

First, we write down the transfer function for the PI controller as provided:

$$G_R(s) = K \left(1 + \frac{1}{sT_i} \right)$$

where K is the controller gain and T_i is the integral time.

Given the process transfer function $G_P(s)$ as:

$$G_P(s) = \frac{1}{(1+2s)(1+3s)}$$

The closed-loop transfer function from R to Y is defined as:

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

Substituting $G_R(s)$ and $G_P(s)$ into $G(s)$ gives us:

$$G(s) = \frac{K \left(1 + \frac{1}{sT_i} \right) \cdot \frac{1}{(1+2s)(1+3s)}}{1 + K \left(1 + \frac{1}{sT_i} \right) \cdot \frac{1}{(1+2s)(1+3s)}}$$

Correct start

Expanding and simplifying this expression will give us $G(s)$ in the desired form. Let's proceed to do the calculation and get $G(s)$ with the denominator in the form of $s^n + a_1s^{n-1} + \dots + a_{n-1}s + a_n$.

Error analyzing

Error

Wrong

Hallucinates a 5th order term

Very wrong answer

It seems there was an error in the calculation. I made a mistake by trying to expand only the denominator directly. Instead, I should handle the fraction properly before expanding. Let's correct this and calculate the closed-loop transfer function again, ensuring that we obtain the denominator in the proper expanded form. [↩]

The simplified denominator of the closed-loop transfer function $G(s)$ is given by:

$$K \left(1 + \frac{1}{T_i s} \right) \left(\frac{1}{(2s+1)(3s+1)} \right) + 1$$

To express this in the standard polynomial form, we'll multiply out the terms and combine like terms. Let me proceed with this step. [↩]

The expanded denominator of the closed-loop transfer function $G(s)$, when written as a single fraction, is:

$$6KTis^3 + 5KTis^2 + KTis + 6Ks^2 + 5Ks + K + 6Tis^3 + 5Tis^2 + Tis$$

We need to combine the terms to get the final denominator in the standard polynomial form.

Let's perform that combination to obtain the coefficients a_1, a_2, \dots, a_n . [↩]

The combined and simplified denominator of the closed-loop transfer function $G(s)$ is:

$$6KTis^3 + 5KTis^2 + KTis + 6Ks^2 + 5Ks + K + Tis(6s^2 + 5s + 1)^2$$

To express this in the standard polynomial form, we need to further combine like terms by distributing the Tis term and adding the coefficients for each power of s . Let's finalize this step to get the denominator in the form of $s^n + a_1s^{n-1} + \dots + a_{n-1}s + a_n$. [↩]

The final form of the denominator of the closed-loop transfer function is:

$$36Tis^5 + 60Tis^4 + (6KTi + 37Ti)s^3 + (5KTi + 6K + 10Ti)s^2 + (KTi + 5K + Ti)s + K$$

This polynomial represents the denominator of the closed-loop transfer function $G(s)$ from the setpoint R to the measurement signal Y . It is expressed in the standard form with coefficients for each power of s . The coefficients are functions of the controller parameters K and T_i , as well as inherent constants from the expansion. This form is useful for analyzing the stability and dynamic response of the controlled system. [↩]



C: Maximum P-gain

$$36Tis^5 + 60Tis^4 + (6KTi + 37Ti)s^3 + (5KTi + 6K + 10Ti)s^2 + (KTi + 5K + Ti)s + K$$

with $Ti = 1$, we can form the Routh array and apply the criterion to find the range of K . Let's perform this calculation to find the largest value of K that maintains stability.

The coefficients of the characteristic polynomial in descending powers of s are:

$$36, \quad 60, \quad 6K + 37, \quad 5K + 16, \quad K + 6, \quad K$$

To ensure stability using the Routh-Hurwitz criterion, the first column of the Routh array (which contains these coefficients) must all be positive. This is necessary but not sufficient for stability; the sufficient condition requires no sign changes in the first column of the Routh array.

For the coefficients given, we must have:

1. $36 > 0$ (which is true for all K)
2. $60 > 0$ (which is also true for all K)
3. $6K + 37 > 0$
4. $5K + 16 > 0$
5. $K + 6 > 0$
6. $K > 0$

Establishes (wrong) conditions

Checks necessary criterion

From conditions 3, 4, and 5, we can solve for the values of K that satisfy these inequalities. The largest K that satisfies all conditions will be the upper limit for K to maintain stability. Let's calculate these limits. [-]

The conditions for K to satisfy stability based on the Routh-Hurwitz criterion are:

1. $K > -\frac{37}{6}$
2. $K > -\frac{16}{5}$
3. $K > -6$
4. $K > 0$

Concludes $K > 0...$

Since K must be positive, the most restrictive condition that satisfies all inequalities is $K > 0$. However, we are interested in the largest value of K that maintains stability. To find this, we would typically look for the critical value of K where the system is on the verge of instability.

Asks Ruth to please use python

If you have access to such tools, you could use the `root_locus` function to plot the root locus and find the critical value of K . If you need to proceed analytically or would like to know how to do it manually, it would involve solving for the conditions where the transfer function crosses the imaginary axis from the left half-plane to the right half-plane.

If you're interested, I can guide you through the steps you'd take to find this using a tool like MATLAB or Python's Control Systems Library, or I can explain the theoretical steps for a manual approach. Please let me know how you'd like to proceed. [-]

You
Could you try to analyse this one more time?

Ruth retries

Data Analyst

I will reattempt the analysis for question 4.c, where we want to determine the largest gain K that can be used in a PI controller to ensure an asymptotically stable closed-loop system, given that $T_i = 1$.

The previous steps have given us the characteristic equation of the closed-loop system, with the coefficients of s in the characteristic polynomial being dependent on K . To ensure asymptotic stability, all the roots of the characteristic polynomial must have negative real parts, which we can

D: Choice of controller

2 Data Analyst

In the context of temperature control in office spaces, a PI controller is often chosen for its ability to eliminate steady-state error due to its integral component and to provide a proportional action that responds to the current error. However, whether to recommend a different type of controller depends on several factors related to the specific control objectives and performance requirements, as well as the nature of the system being controlled. Here are some considerations:

1. **PID Controller:** A PID (Proportional-Integral-Derivative) controller might be recommended if there is a need for improved transient response and reduced overshoot. The derivative component provides a prediction of future errors and can help dampen the system response, leading to faster settling times without significant overshoot. If the temperature control system experiences frequent and large disturbances or is required to respond quickly to changes in setpoint, a PID controller could be beneficial.

”Correctly” suggests PID

2. **Lead or Lag Compensators:** If the system requires specific shaping of the frequency response for stability or performance, lead or lag compensators might be introduced. A lead compensator can increase the system's phase margin, improving stability and transient response, while a lag compensator can improve steady-state accuracy and reduce sensitivity to changes.
3. **Feedforward Control:** If there are measurable disturbances that can be anticipated before they affect the system, a feedforward control strategy could be implemented alongside the PI controller. This can compensate for the disturbances before they impact the system, improving overall control performance.
4. **Adaptive or Gain Scheduling Controllers:** In environments where the system dynamics may change over time, such as in buildings where the occupancy or usage patterns can vary significantly, an adaptive controller or a controller with gain scheduling could be more appropriate. These controllers adjust their parameters in real-time to maintain optimal performance under varying conditions.
5. **State-Space or Model Predictive Control (MPC):** For complex systems where multiple inputs and outputs must be controlled simultaneously, or where the future state of the system needs to be taken into account, advanced control strategies such as state-space control or MPC could be considered. These approaches can handle constraints and multi-variable control problems more effectively than traditional PI control.

Also suggests everything else

The decision to recommend an alternative controller would depend on factors like:

- **Performance:** Is the PI controller meeting the performance specifications in terms of stability, transient response, and steady-state error?
- **Complexity:** Would the company benefit from a more complex controller given the system's dynamics, and can the additional complexity be justified?
- **Cost:** What are the cost implications of implementing a more complex control system, both in terms of hardware and software, as well as the need for specialized expertise?
- **Robustness:** How does the PI controller perform under varying conditions, and is there a need for a more robust control strategy?
- **Maintenance:** Consider the maintenance (↓) operational aspects of introducing a more complex controller.

There are an array of alternative controllers.

Summary

Total: 12.5 / 25
Passing grade: 12

Q	Description	GPT-answer	Ruth interaction	Score
1	ODE to state space, discuss stability	Correct	Asked Chat-GPT to double-check its' own answers.	2.5 / 2.5
2	Nonlinear Lotka-Volterra ODE. Find stationary points. Linearize and analyze.	Correct equilibria, linearization and stability analysis. Did not design feedback law L.	Failed to realize that 2d was only a recipe, and not an actual answer.	4.5 / 6.5
3	Match transfer function to nyquist plots. Find gain margins. Image heavy.	Mismatches some plots. Provides no explicit gain margins.	Seems to realize something is missing in 3b, fishes for further answers.	0.5 / 4
4	Find closed-loop TF, find stable controller parameters. Calculation heavy. Recommend better controller structure.	Fails with calculations (appears to use sympy). Repeated "error analyzing". Very many recommended controllers in answer. Finally provides (incorrect) solution to closed loop system.	Double checks that solution matches block-diagram. Reprompts to try and get through errors.	0.5 / 4
5	Pole placement of state-space plant. Why do we need an observer?	MANY errors with symbolic python crashes.	Reprompts while keeping context. Proposes using python for calculation.	1.5 / 1.5
6	Identify cascade and feed-forward structure in block-diagrams. Compare the two structures.	Correctly identifies structures , but misses 6d.		1.5 / 2
7	Phase and amplitude margins in bode plots. Design a compensator for increased phase margin.	Reads margins, but wrong. Provides "how to"-instructions for reading margins and designing compensators.	Prompts to check that answers are relevant, but fails do double-check plots.	1.5 / 4.5

Observations

Ruth was good at:

- Splitting questions into steps
- Making Chat-GPT check its' own answers
- Maintaining question context
- Suggesting the use of numerical tools

Ruth did not (which a student might):

- Correctly identify when the questions were not fully answered
- Double-check calculations
- Read plots
- Identify when numerical tools are unnecessary

The errors that LLMs make

Capabilities of Large Language Models in Control Engineering: A Benchmark Study on GPT-4, Claude 3 Opus, and Gemini 1.0 Ultra

Darioush Kevian¹, Usman Syed¹, Xingang Guo¹, Aaron Havens¹,
Geir Dullerud¹, Peter Seiler², Lianhui Qin^{3,4}, and Bin Hu^{*1}

¹University of Illinois Urbana-Champaign

²University of Michigan

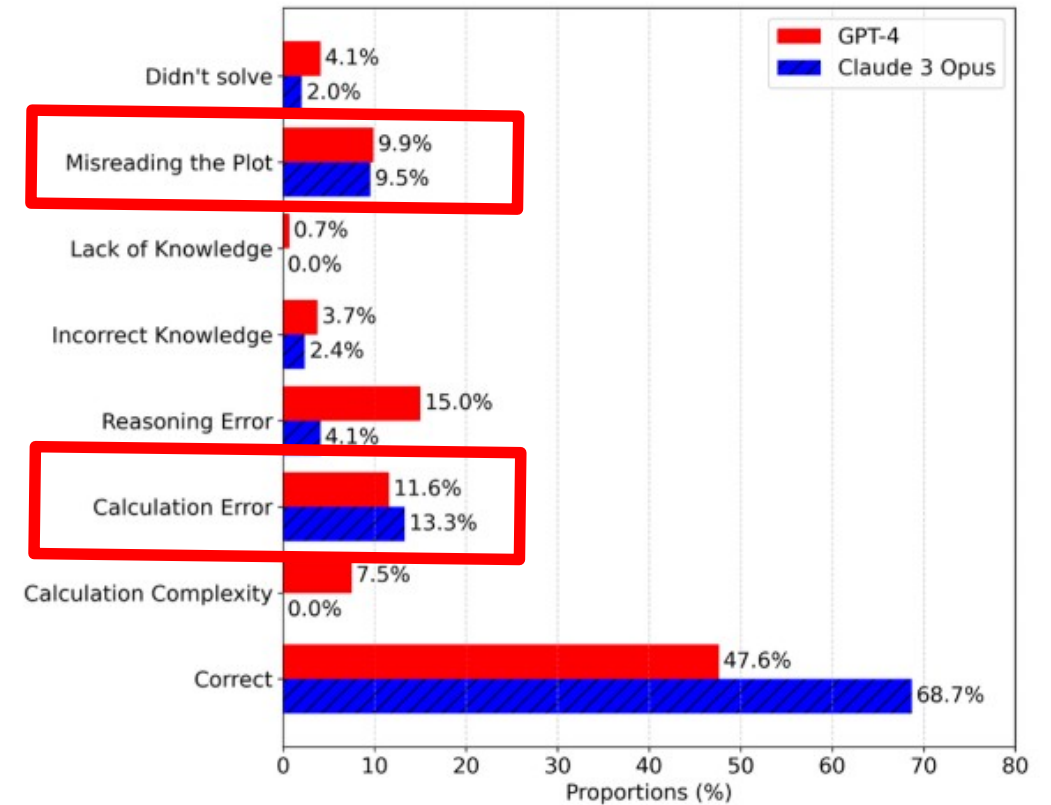
³Allen Institute for AI

⁴University of California San Diego

* Corresponding author. E-Mail: binhu7@illinois.edu



Topic	# of Problems	# Visual
Background	28	0
Stability	19	0
Time response	21	3
Block diagrams	5	5
Control System Design	24	0
Bode Analysis	15	13
Root-Locus Design	7	1
Nyquist Design	5	4
Gain/Phase Margins	9	0
System Sensitivity Measures	3	0
Loop-shaping	4	0
Advanced Topics	7	0
Total	147	26



Thank you!

Questions?

Discussion?