Challenge Deliverable 5
Answer form

4DB00 Dynamics and Control of mechanical systems
2019-2020

Name:	Jelle Langedijk
Student number:	1315358

Be aware of the TU/e Code of Scientific conduct. See: https://www.tue.nl/en/our-university/about-the-university/organization/integrity/scientific-integrity/.

Question a):

Plot the Nyquist curves of the open-loop systems $L_i(s)$—with $i = 1,2,3$—by using the "Nyquist" function in Matlab. Add the requested plot here.

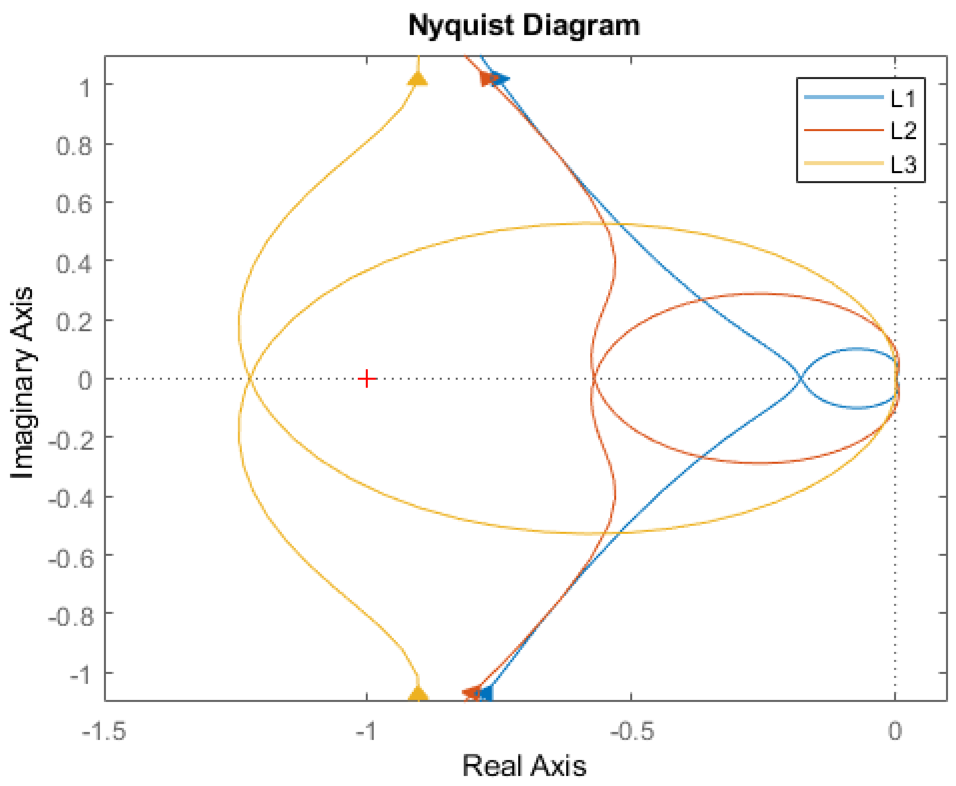

Figure 1: Nyquist plot of the three open-loop systems.

Question b):

Use the Nyquist curves from question a to determine, for each controller, whether the closed-loop interconnection is stable. Please explain how you came to this conclusion.

To answer this question, I will use the Nyquist Criterion:

$$Z = N + P$$

Where

- Z is the number of unstable poles of Closed Loop transfer function $T_i(s)$;
- P is the number of unstable poles of the Open Loop transfer function $L_i(s)$;
- N is the number of encirclements in clockwise direction that the Nyquist contour makes around (-1;0).

The closed-loop interconnection of $C_1(s)$ with $G_l(s)$...

Using the `pole(T1), pole (L1)` commands in MATLAB respectively gives me:

Z = 0
P = 0
Looking at the Nyquist contour in figure 1:
N = 0

Since these values agree with the Nyquist Criterion, this closed loop intersection is stable.

The closed-loop interconnection of $C_2(s)$ with $G_l(s)$...

Using the `pole(T2), pole (L2)` commands in MATLAB respectively gives me:

Z = 0
P =0
Looking at the Nyquist contour in figure 1 :
N = 0

Since these values agree with the Nyquist Criterion, this closed loop intersection is stable.

The closed-loop interconnection of $C_3(s)$ with $G_l(s)$...

Using the `pole(T3), pole(L3)` commands in MATLAB respectively gives me:

Z = 2
P = 0
Looking at the Nyquist contour in figure 1:
N = 2

Since Z is unequal to zero, this closed loop intersection is unstable.

Question c):

For each open-loop system $L_i(s)$—with $i = 1,2,3$—determine the crossover frequency ω_c in rad/s, the phase margin PM in degrees, the gain margin GM in dB and the modulus margin MM in dB.

Using the `margin(…) = [Gm, Pm, Wcg, Wcp]` command in MATLAB, and using the knowledge that:

$$1/MM \models \max_{\omega} |S(j\omega)|$$

I obtain:

For $L_1(s)$ we get:
$\omega_c = 0.2$ rad/s
$PM = 49.9714$ °
$GM = 20log(5.5850)$ dB = 14.94 dB
$MM = |\,20log(0.6755)\,|$ dB = 3.41 dB

For $L_2(s)$ we get:
$\omega_c = 0.3998$ rad/s
$PM = 50.0335$ °
$GM = 20log(1.7507)$ dB = 4.86 dB
$MM = |\,20log(0.4262)\,|$ dB = 7.41 dB

For $L_3(s)$ we get:
$\omega_c = 1.1446$ rad/s
$PM = -26.2166$ °
$GM = 20log(0.8170)$ dB = -1.76 dB
$MM = |\,20log(0.2151)\,|$ dB = 13.35 dB

Question d):

Determine the response of the closed-loop interconnection between the “virtual test setup” and each controller, for a constant velocity reference signal. Utilize the “Sim_Control” request within the DOMS toolbox for this purpose. Use the simulation conditions as described in the deliverable and add the requested plot here.

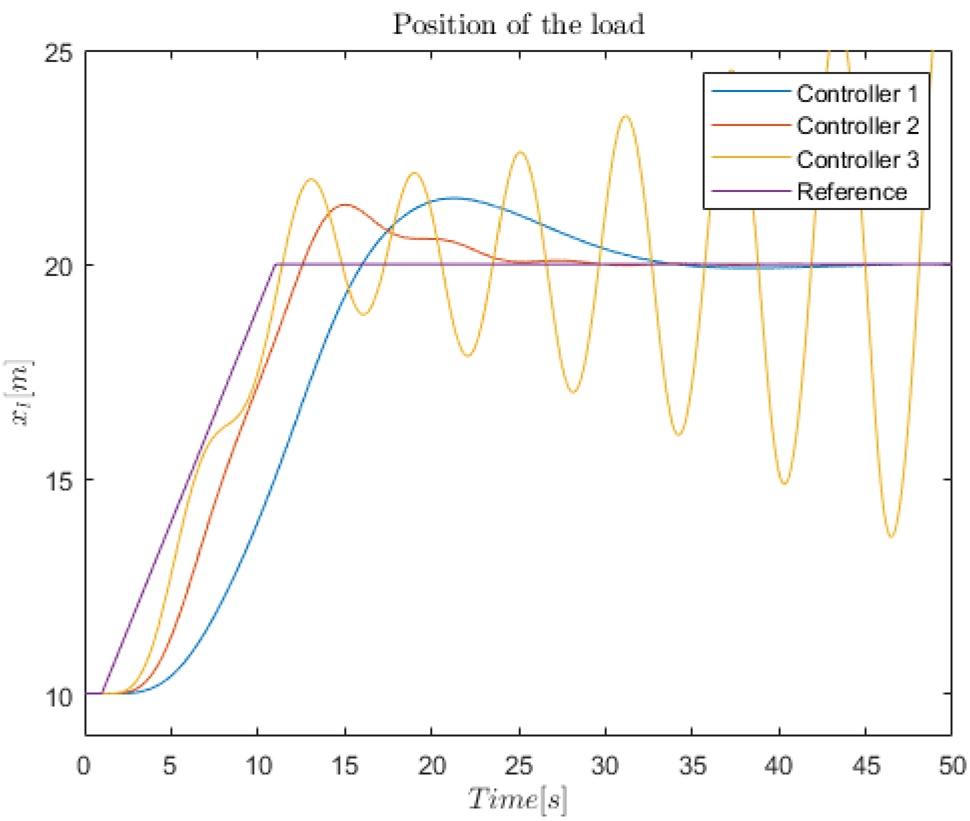

Figure 2: Response with constant velocity signal and three controllers.

Question e):

How well is each controller able to track the reference signal in question d? Based on this performance, which of the three controllers would you recommend?

Controller 1

This controller seems to be able to track the reference signal quite well but too slow. It also overshoots the maximum value of the reference signal (20 [m]) with a value of roughly 1 [m] and needs about 30 [s] to fully stabilize at the 20 [m] line.

Controller 2

This controller performs better than controller 1. It tracks the reference signal "quicker" and takes about 10 [s] less to fully stabilize at the 20 [m] line. It however, also overshoots with roughly 1 [m].

Controller 3

This controller has visibly the lowest tracking performance of all three controllers. It does not follow the straight line of the reference at all, but follows the line quite "jerky" and eventually follows a very unstable path, in contrast to the stabilization at 20 [m] that is obviously preferred.

Conclusion

This, trivially , makes controller 2 the controller to recommend, since it has the best tracking performance of the three controllers.

NOTE: The behavior of controller 3 should be foreseen, since I determined in b) that this controller is unstable.

Question f):

Repeat the simulations in question d with the reduced damping coefficient d_W and add the requested plot here.

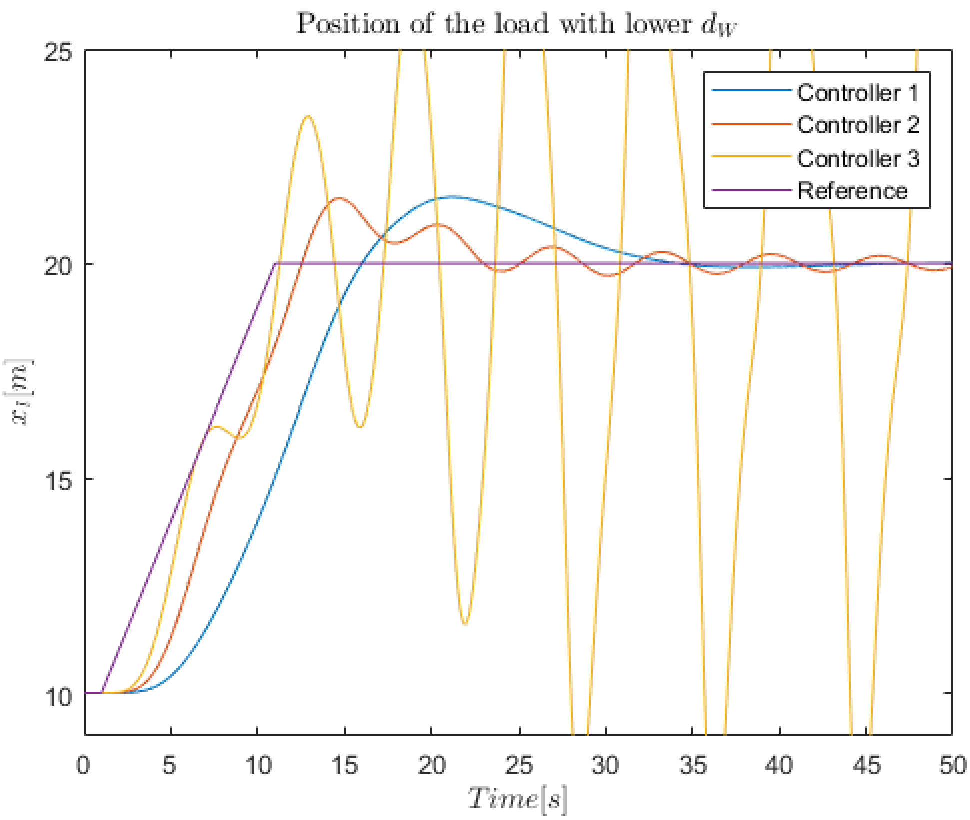

Figure 3: Response with constant velocity signal and three controllers with a load with lower air friction.

Question g):

How well is each controller able to track the reference signal with the reduced camping coefficient d_W and what does this say about robustness? Based on these new results, which of the three controllers would you recommend?

Controller 1

This controller seems to be able to track the reference signal quite well but too slow. It also overshoots the maximum value of the reference signal (20 [m]) with a value of roughly 2 [m] and needs about 30 [s] to fully stabilize at the 20 [m] line.

Compared to figure 2, controller 1 shows a very similar trajectory in figure 3, which makes it very robust.

Controller 2

This controller performs worse than controller 1. It tracks the reference signal “quicker” and also overshoots with roughly 1 [m]. But, it does not seem to stabilize at the 20 [m] line, but keeps oscillating around this line with a - on this interval – seemly small constant amplitude.

Compared to figure 2, controller 2 shows a initially a very similar trajectory in figure 3, but eventually derives from this similarity by oscillating around the 20 [m] line, which makes it less robust than controller 1.

Controller 3

This controller has visibly the lowest tracking performance of all three controllers. It does not follow the straight line of the reference at all, but follows the line quite “jerky” and eventually follows a very unstable path (more unstable than before in figure 2), in contrast to the stabilization at 20 [m] that is obviously preferred.

Compared to figure 2, controller 3 shows a very similar “jerky” trajectory in figure 3, but explodes even more at about 10 [s] and further. This makes this controller the least robust of all of them.

Conclusion

This, trivially , makes controller 1 the controller to recommend, since it has the best tracking performance of the three controllers and the highest robustness.

NOTE: The behavior of controller 3 should be foreseen again, since I determined in b) that this controller is unstable.

Question h):

Use a similar approach as before, to determine whether or not you would recommend the aggressive controller $C_{aggr}(s)$ for this application. Please comment on stability, tracking performance, robustness and feasibility. You may include *at most* 3 figures in your answer.

With regards to stability the controller can be defined as stable

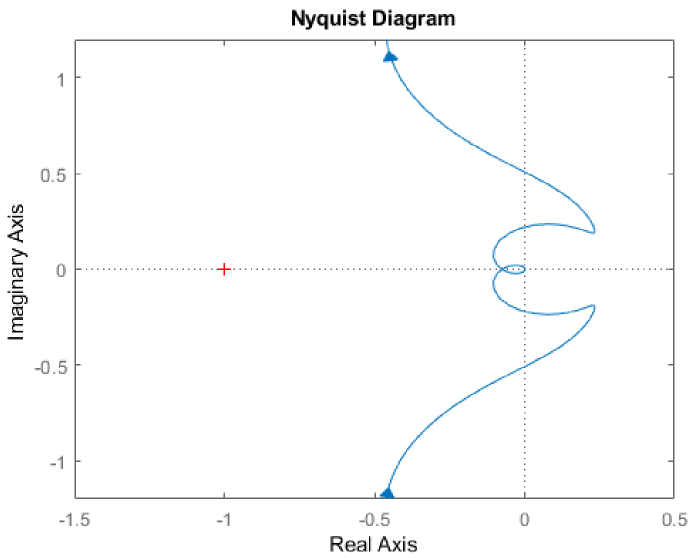

Figure 4: Nyquist contour of the closed loop transfer function with the agressive controller

To support this statement, I will use the Nyquist Criterion:

$$Z = N + P$$

Where

- Z is the number of unstable poles of Closed Loop transfer function $T_i(s)$;
- P is the number of unstable poles of the Open Loop transfer function $L_i(s)$;
- N is the number of encirclements in clockwise direction that the Nyquist contour makes around (-1;0).

Using the `pole(TA), pole (LA)` commands in MATLAB respectively gives me:

Z = 0
P =0
Looking at the Nyquist contour in figure 4:
N = 0

Since these values agree with the Nyquist Criterion, the closed-loop interconnection $L_a(s)$ can be classified as stable.

Question h) (continued):

When it comes to tracking performance, the controller performs very well

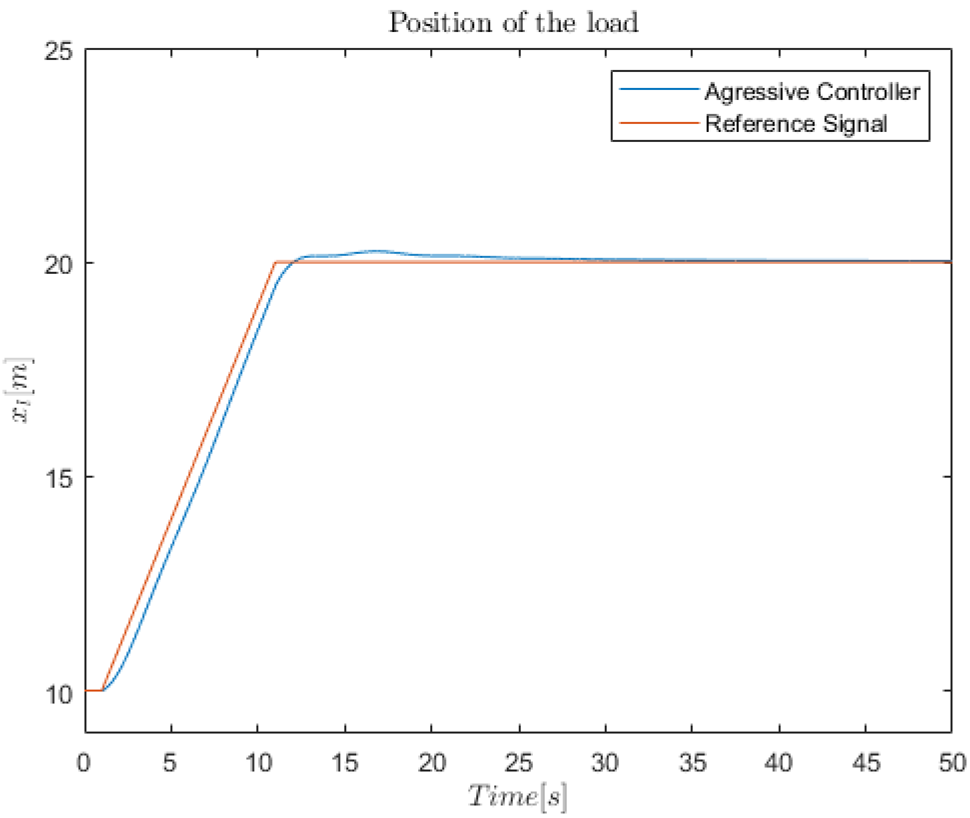

Figure 5: Response with constant velocity signal and agressive controller.

The tracking performance can be called phenomenal. It follows the same trajectory nearly perfect and only has a tiny overshoot, which is stabilized relatively quick.

Robustness of the controller is good

When reducing the value of d_W to 100 again, and making a plot like in figure 5, I get (see next page):

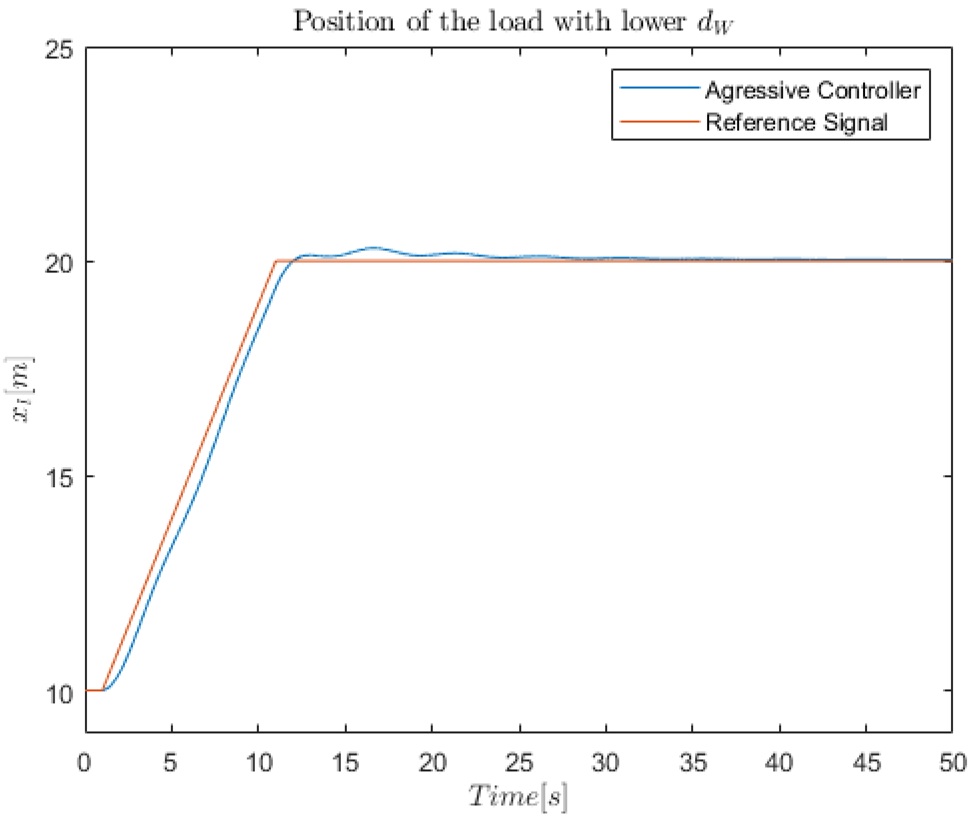

Figure 6: Response with constant velocity signal and agressive controller with a load with lower air friction

The response is, beside two extra bumps during stabilization, identical to the response in figure 5, making the controller quite robust.

Finally, regarding feasibility…

Since C_{aggr} contains fifth order terms (fifth order polynomial in s) in the nominator and denominator, the controller is not a standard P, PID or PD controller (or even second or third order versions of them).
NOTE: It might be a combination of these controllers with each other (which is quite unlikely in practice), or notch filters.

This, foremost, shows us that this kind of controller is probably not used often (or maybe not even at all) in physical dynamical systems. Due to this, designing this controller (maybe also in physical sense, depending on the application) will be more consuming (in time and financial sense).