Technologies for Autonomous Vehicles

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Project 3

June 16, 2024

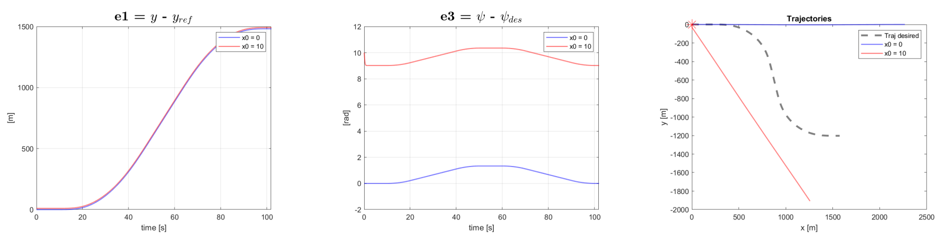
1 Introduction

The aim of this project is to implement a linear state-space formulation of a single-track model suitable for lane keeping and path tracking control, and evaluate its response for various operating conditions. For examples, including a feedforward and/or feedback contribution, introduce an integral control contribution, and also compare with different speeds and different curvature profiles (e.g. skidpad and obstacle avoidance manoeuvres).

2 System behaviour

The matrix A presents 2 zero eigenvalues and 2 negative, so the system is marginally stable. The Feedback gain will change the dynamics of the system making it asymptotically stable.

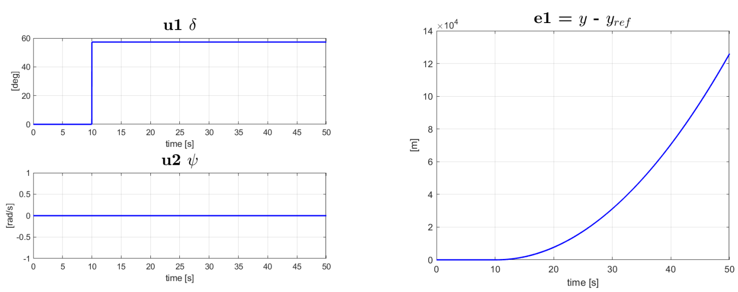
2.1 Different initial conditions



(a) (b) (c)

Figure 1: (a) vehicle starts shifted by 10 m, (b) it starts rotated of 10 rad, (c) shows trajectories. The system is marginally stable: when the input is zero the system remains closer to the initial conditions.

2.2 Step response

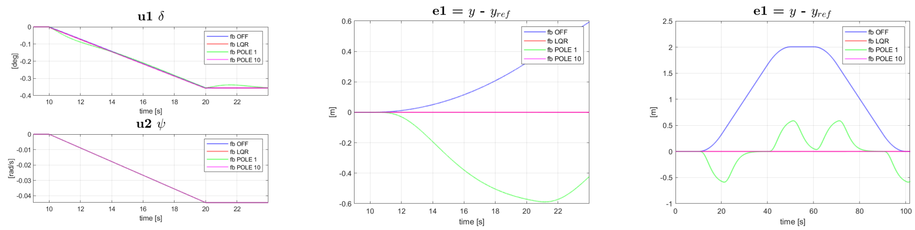


(a) (b)

Figure 2: (a) step input and 0 disturb, (b) the system diverges, so it's not BIBO stable

3 Feedforward and Feedback

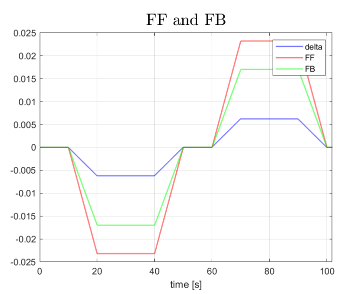
3.1 Feedback ON versus feedback OFF



(a) (b) (c)

Figure 3: fb OFF: open loop controller, fb Pole 1 is tuned with poles too small, fb Pole 10 and lqr are properly tuned. (a) and (b) are zoomed plot to see how a slight change in the input can bring to significant variations in the outcome. (c) is the complete plot of e1: the open loop solution is clearly improved by the feedback contribution (if properly tuned)

3.2 Comparison between feedback and feedforward contribution

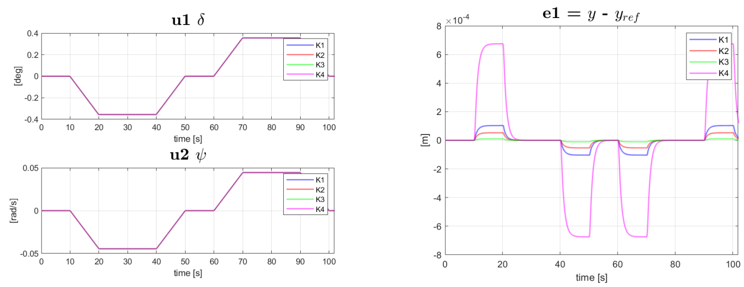


(a)

Figure 4: δ is the difference of the two signals. The feedforward is the strongest signal but needs to be mitigated by the feedback to work at bests

3.3 Tuning the controller

For tuning the control structure, another way besides the pole placement methodology is the linear quadratic control.
It can be seen that as Q increases (or R decreases) the system improves, while on the contrary (k4 in pink) it's sligthly worse.

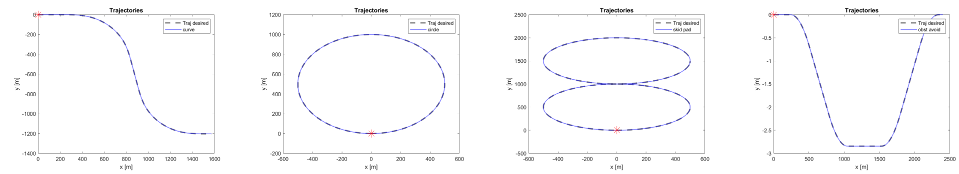


(a) (b)

Figure 5: k1, k2 and k3 are LQR controllers tuned with increasing Q/R matrices weights, while k4 is tuned with lower Q/R. (a) doesn't show significant variations in the input, while in (b) we can see that giving more weight to the state is more effective for the controller's response.

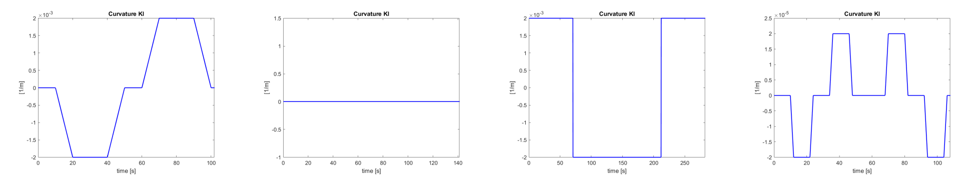
4 Curvature profiles

This test aims to demonstrate how the model, (with the right parameters?), responds well even in different trajectories as: simple curve already seen in previous tests, a total 360 degree curvature, skidpad and obstacle avoidance manoeuvres.



(a) (b) (c) (d)

Figure 6



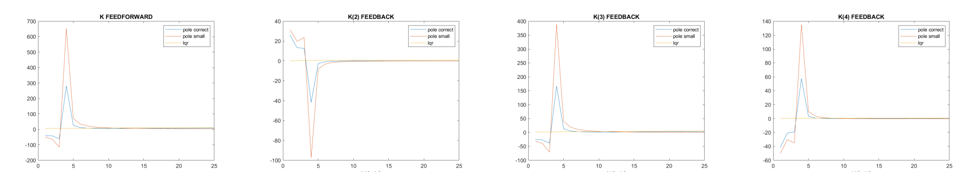
(a) (b) (c) (d)

Figure 7

5 Different speeds

Up to now all the tests have been done with a constant speed equal to 80 $\frac{km}{h}$, now we will compare how it behaves at higher speeds, in particular at 160 $\frac{km}{h}$ and 220 $\frac{km}{h}$
It is clear that at lower speeds it works better than at high ones.

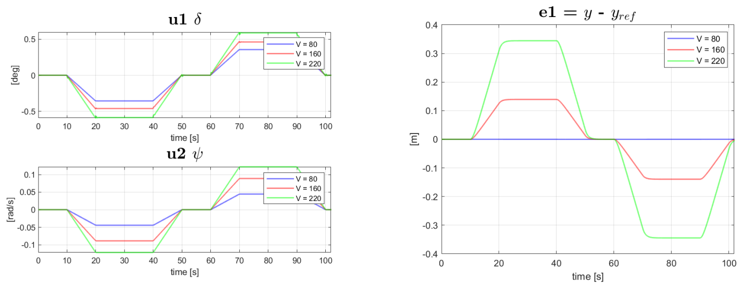
5.1 K FB and FF when V varies



(a) (b) (c) (d)

Figure 8: here it can be seen how the gains changes at different speeds. $K(1)$ FB relative to e_1 is constant during this test. It settles at 0.4, 0 and 1 for the 3 type of controller tuning we tried so we didn't plot it. there is a peak at V=4 m/s that is probably a singularity of the system.

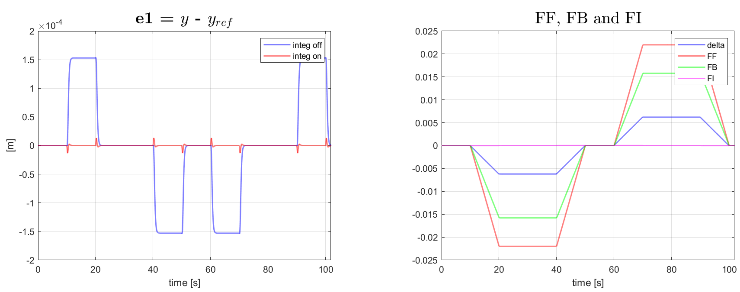
5.2 Simulations with different V



(a) (b)

Figure 9: At higher speeds the controller struggles a little but manages to track the trajectory. notice in (a) that a greater input is needed to complete the same task.

6 Integrative term

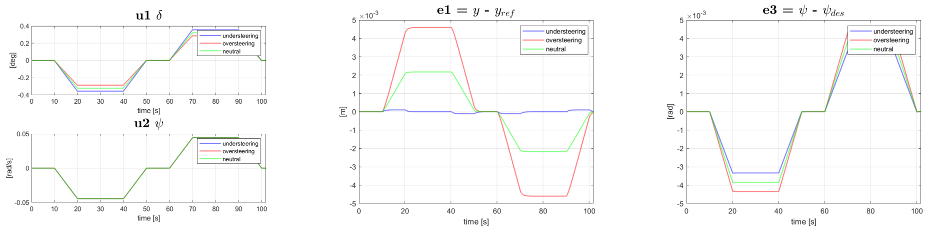


(a)

Figure 10: We introduced an integrative term : $I = -K_I \cdot e_1(t)$. K_I is tuned with the other states with the feedback formula and a fifth state $e_5(t) = \int e_1(t)dt$. It increases the speed of convergence of the system with the side effect of adding a little oscillations. (b) the contribution of I is very small.

7 Variation of car behaviour

Oversteering occurs when a motor vehicle turns more than a driver appears to command when at the steering wheel. On the flip side, understeering occurs when an automobile turns less than what is anticipated through the command at the wheel given by a driver. This issue is the result of the difference in slip angle between the rear and front wheels.

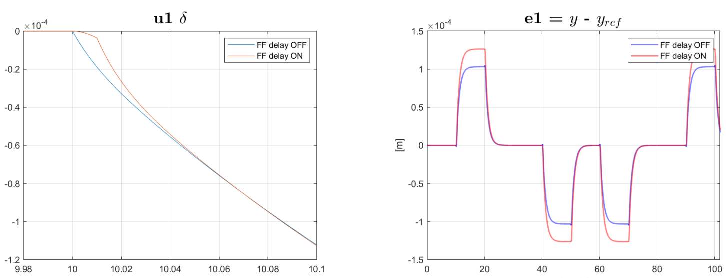


(a) (b) (c)

Figure 11: We computed the values of Cf, Cr, a and b to make the vehicle understeer, oversteer and be neutral. What can be seen is that the understeering vehicle performs better but needs more input energy to complete its task.

8 FF Delay

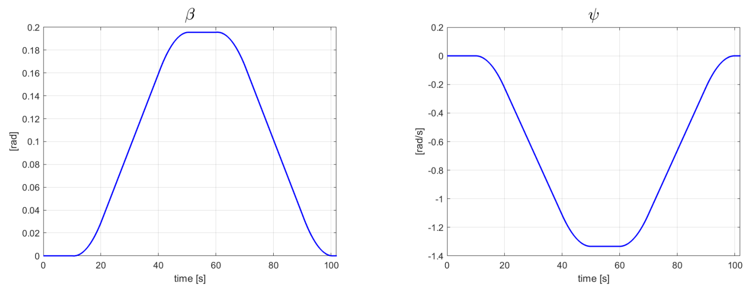
Let's consider the effect of the presence of a pure time delay of 0.01 s for the generation of the feedforward control input.



(a) (b)

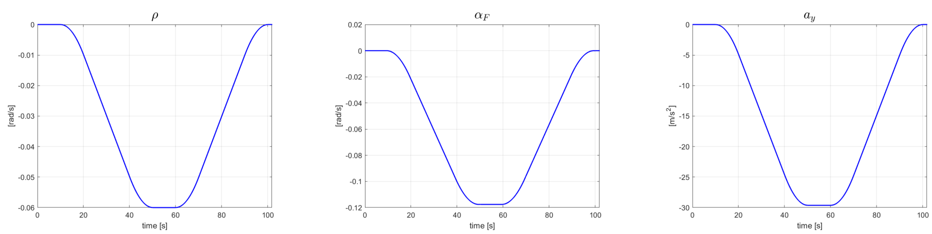
Figure 12: The delay slows the response of the controller, shown in (a) zoomed and in (b) it's effects.

8.1 Other variables β, ψ, ρ, α_F, a_y



(a) (b)

Figure 13



(a) (b) (c)

Figure 14