Technologies for Autonomous Vehicles Assignment 2

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1 Introduction

This report aims to summarize and comment the developed work and models in the context of the second assignment for Technologies and Autonomous Vehicles.

2 Model Layout

2.1 Acceleration Scenario

In the upper part of the model the generation of torque is represented: the input block is a ramp representing the increasing pressure on the accelerator pedal. If we choose an high slope for such ramp (we have chosen 500), we obtain a **step in** simulation because of the steep ramp. The input is delayed by the motor pure time delay and transformed by a first order transfer function with the purpose of simulating the dynamic response of the motor.

The motor speed is computed by multiplying the wheels' angular speed by the transmission ratio. A switch block uses the motor's speed to determine if the output motor torque is the maximum one in the constant torque region or the one depending on the maximum motor power in the constant power region.

The output motor torque is multiplied by the transmission ratio and by the efficiency of the transmission to obtain the torque applied on the two driving wheels. Thus, it is multiplied by 0.5 to obtain the torque at each single wheel.

In the middle region there is the rear wheel dynamics.

The **wheel_F** subsystem is used to compute longitudinal tyre force and wheel's angular speed, based on four inputs computed in this way:

1. Tm = torque available at the wheel, delivered by the motor;
2. Tb = braking torque
3. Fz_wheel_i = vertical tyre load depending on dynamic load transfer; the dynamic contribution due to acceleration and is summed(with sign, that

depends on the acceleration) to the rear wheel static load and subtracted from the front wheel static load.

4. v_x = feedback loop of the linear wheel speed

The longitudinal tyre force is computed using Pacejka magic formula. The wheel's angular speed is computed taking into account also the motor torque, the braking torque and the rolling resistance in the subsystem following the Pacejka block.

The front (non-driving) wheel dynamics is reproduced in the bottom part of the model: it is made of the same blocks of the driving wheel, but the given motor torque is a constant zero.

The Fx computed by the mentioned subsystems are given as input to **Vehicle_F** subsystem in which each tyre force is multiplied by two to take into account the two pairs of wheels and then the aerodynamic drag force is subtracted from the total force.

The net resulting force is divided by the equivalent mass of the vehicle (to take into account the rotating parts) to obtain the instantaneous acceleration and the corresponding speed of the vehicle.

2.2 Braking Scenario

The Simulink layout for this scenario is similar to the previous one. Here the differences:

1. The input pedal is represented by two signals: this allows to emulate the release of the pedal by suppressing the "pedal on" signal;
2. A block to stop the simulation when the car speed reached zero has been introduced;
3. The **ABS** system: it is implemented by a Matlab function that halves the output braking torque and the regenerative braking torque in case the slip ratio is above 0.12 (this threshold has been chosen considering that the simulation is done on a dry tarmac).
4. a switch block has been introduced to swap the sign of the motor torque whenever the braking signal is greater than 0 to simulate the regenerative braking torque.

3 Simulation

3.1 Acceleration Scenario

The simulation is performed giving a steep ramp as accelerator input pedal. The curve of vehicle speed in (**Figure 1**) has an exponential behaviour in the first seconds and an asymptotic behaviour in the remaining part of the simulation. The limit speed of 150km/h is reasonable given the characteristics of the vehicle.

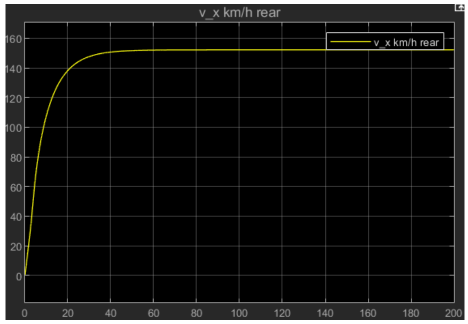

Figure 1: Vehicle speed during acceleration test

The result is coherent with the expectations: at the beginning the first order dynamics is visible, while at the end we reach a constant speed.

If we look at the curve of the torque produced by the engine (**Figure 2**), we can distinguish between the max torque and max power regions.

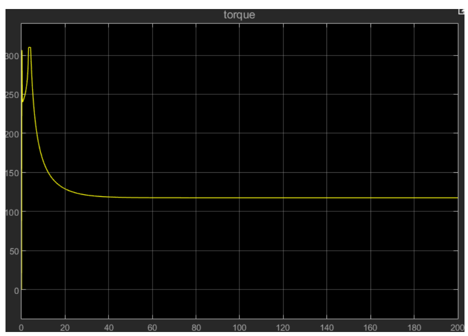

Figure 2: Torque delivered by the engine during acceleration test

The irregularities in the max torque region are due to the wheel spinning, as we can see in the wheel's slip ratio curve (**Figure 3**). The slip is caused by the fact that the wheel is starting to rotate at high speed when the vehicle is standing still.

If we try to reduce by a factor of four the slope of the ramp representing the input pedal and we also saturate the ramp to a value of 0.5 instead of 1, we can see that the slip reduces significantly (**Figure 4**) and that the torque characteristic become equal to the ideal one (**Figure 5**). But, as we can see from **Figure 6**, with such conditions, the vehicle takes more time to accomplish the acceleration phase, ending with a lower constant speed.

From **Figure 7** to **Figure 10** we can observe the power losses during the test due to different contributions.

To compute the achievable ranges at different constant speeds, we used this strategy:

1. We saturated the accelerator pedal to a value less than 1 (which represents the maximum value) such that the vehicle reaches the desired constant speed;

2. From the simulation of the response to such an input, we measure the power value absorbed by the engine once reached the constant speed;

3. We divided the battery capacity by this power value and then we multiplied by the speed;

In **Figure 11** there are the result of the computations for three different speeds, included the maximum one.

3.2 Braking Scenario

Since we want to use regenerative braking, in the current simulation also the braking pedal is given as input to the engine as a ramp (to represent a smooth braking), so the engine keeps working (but by means of signal connected to the braking pedal the torque in this case becomes negative). We decided to have the vehicle accelerating for some time, then we simulated the release of the acceleration pedal and the pressure of the braking one after some seconds. So the vehicle undergoes two decelerating phases: one in which no torque is applied and the engine slows down by action of inertia and one in which braking torque is applied also as regenerative braking torque.

In **Figure 12** there is the speed profile until the vehicle stops.

In **Figure 13** we can observe the level of recuperated energy thanks to regenerative braking.

The ABS activates as we can see in **Figure 14** int the last few seconds of the braking simulation, by cutting the overall braking torque because of the tyre slipping (**Figure 15**). From **Figure 14** we can still observe the different delays that affect the braking system and the regenerative braking system, while we can see that the sum of each braking contribution (in absolute value) builds the braking torque: this is the behaviour of regenerative braking type B phased. From **Figure 16** we can see as, while the rear longitudinal force is greater during acceleration, the braking front longitudinal force is greater during deceleration, ensuring a stable maneuver.

The stopping distance is obtained by integrating along time the speed during the braking maneuver and is plotted in **Figure 17**. It is far smaller than the regulation's limit.

3.3 Emergency Braking Scenario

In this scenario, an emergency braking event is simulated: no regenerative braking is applied and the vehicle is slowed down by the action of the hydraulic brakes only; thus, no input is provided to engine after accelerator is released. The braking torque is applied by means of a step at t=50s.

In **Figure 18** we can see the speed profile.

The results of the emergency braking simulation are quite similar to the non-emergency one, with the difference that a greater stopping distance is required (**Figure 19, 20, 21**)

All those results were obtained with a dry asphalt friction coefficient ($\mu = 0.9$). If we suppose instead to have wet conditions (wet asphalt friction coefficient $\mu = 0.6$), we obtain the results plotted in **Figure 22** and **Figure 23**.

Accordingly to our expectations, the stopping distance increases in wet conditions. If we reduce the slip threshold embedded into the ABS from 0.12 to 0.09 in order to anticipate the activation, we can obtain a lower stopping distance (**Figure 24**).

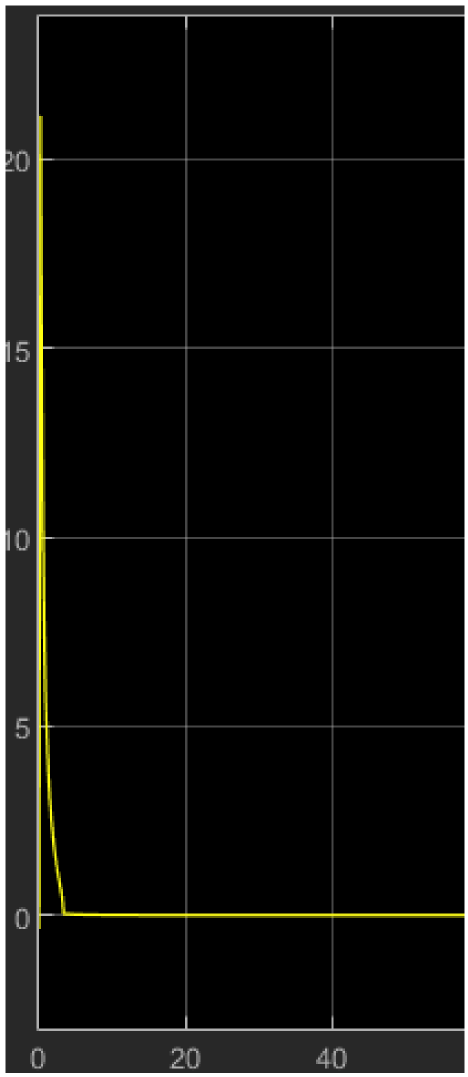

Figure 3: Wheel's slip ratio at the beginning of the acceleration test

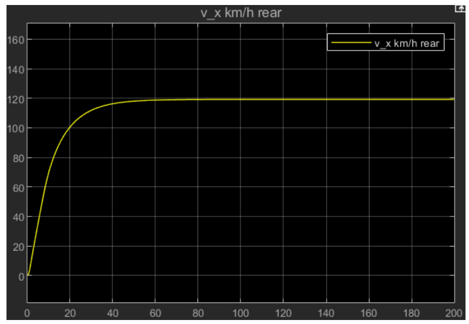

Figure 4: Vehicle speed with reduced input pedal ramp slope and saturation

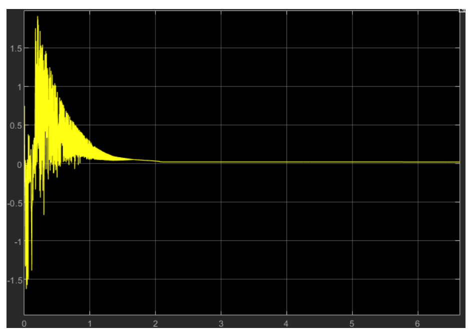

Figure 5: Slip with reduced input pedal ramp slope and saturation

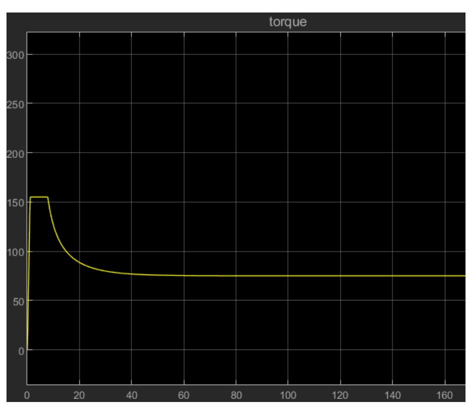

Figure 6: Motor torque with reduced input pedal slope ans saturation

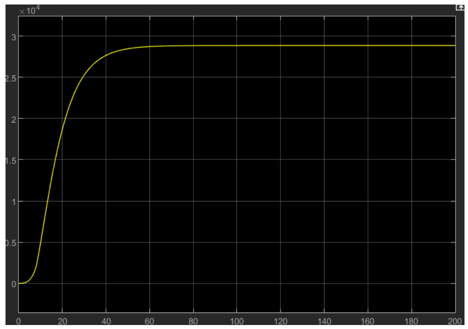

Figure 7: Aerodynamic power loss

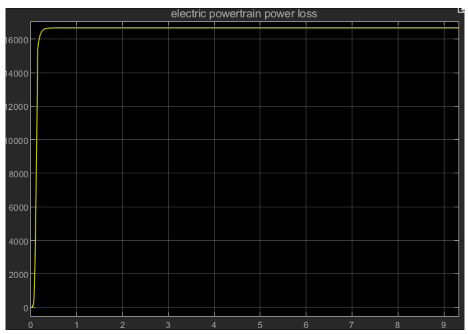

Figure 8: Power train efficiency power loss

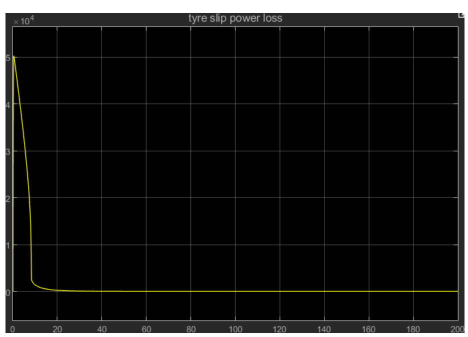

Figure 9: Power loss due to tyre slip behaviour during acceleration: it is relevant only during the beginning of the simulation

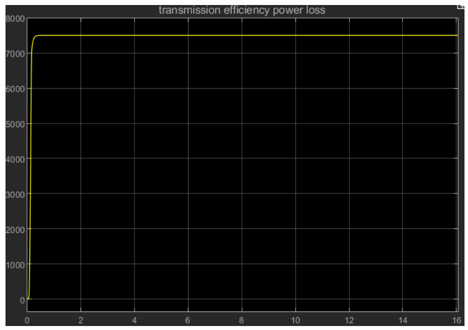

Figure 10: Power loss due to transmission efficiency during acceleration test

```
%% achievable range at different constant speeds

vel1 = 50;
vel2 = 100;
vel3 = 152.1; %vmax

p1 = 0.095e5;
p2 = 0.5e5;
p3 = 1.667e5;

achievable_range_at_50kmh = batt_cap/p1*vel1
achievable_range_at_100kmh = batt_cap/p2*vel2
achievable_range_at_Vmax = batt_cap/p3*vel3
```

Command Window

New to MATLAB? See resources for Getting Started.

```
achievable_range_at_50kmh =

  305.2632


achievable_range_at_100kmh =

  116.0000


achievable_range_at_Vmax =

   52.9202
```

Figure 11: Computations of achievable ranges at different constants speeds

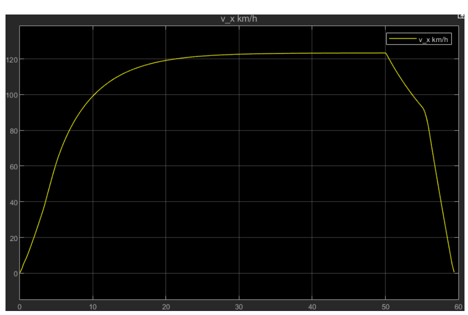

Figure 12: Speed profile during braking simulation

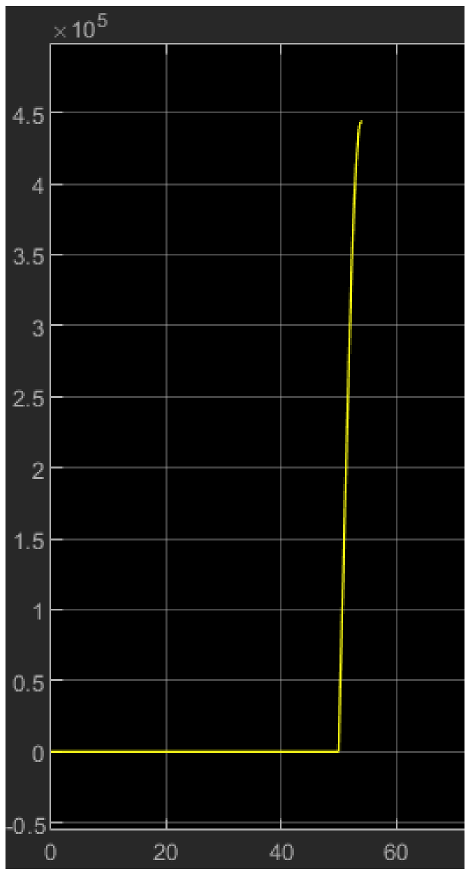

Figure 13: Recuperated energy thanks to regenerative braking

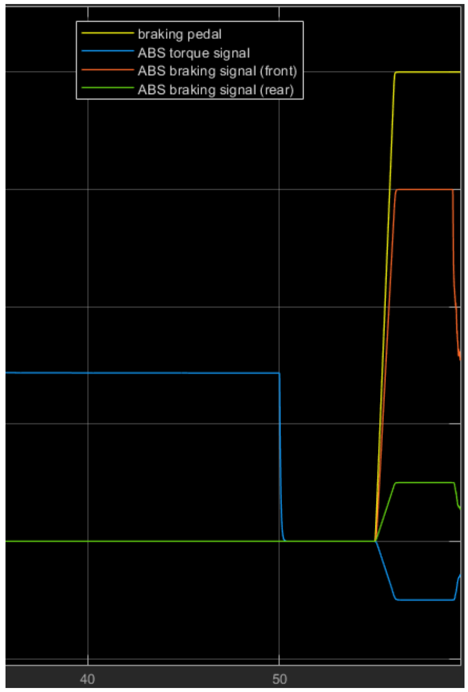

Figure 14: braking signal vs. ABS output signal

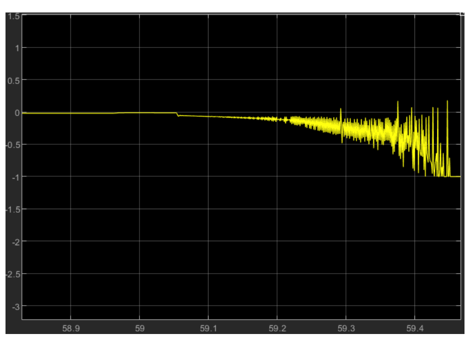

Figure 15: tyre slip during the end of the braking simulation

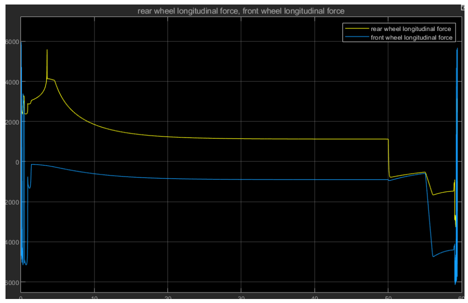

Figure 16: longitudinal tyre forces during braking simulation

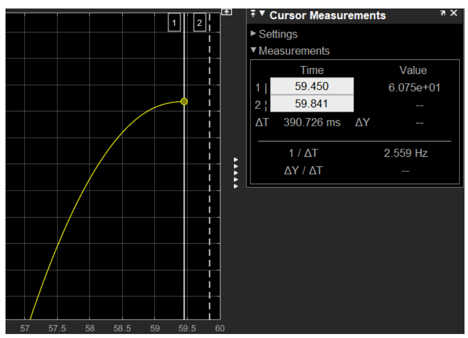

Figure 17: stopping distance during braking simulation

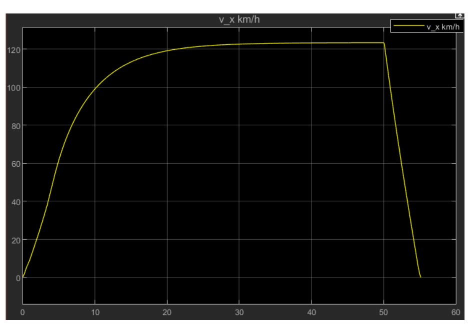

Figure 18: speed during emergency braking simulation

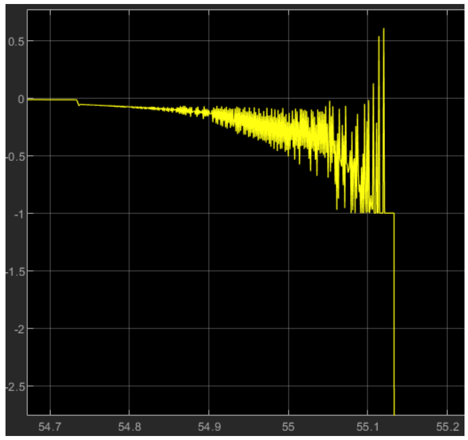

Figure 19: (rear) tyre slip during emergency braking simulation

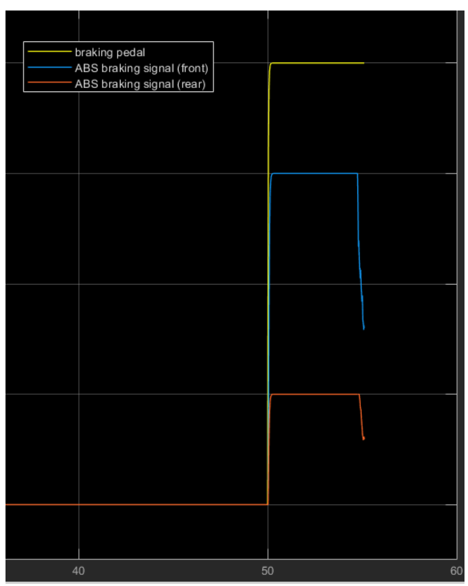

Figure 20: ABS output signals during emergency braking simulation

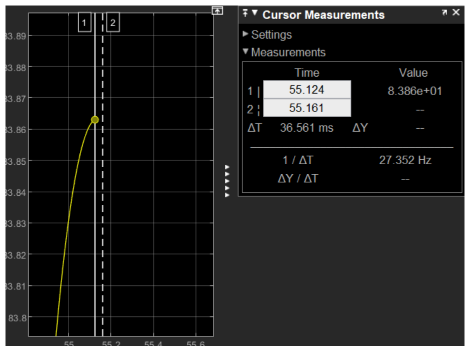

Figure 21: stopping distance during emergency braking simulation

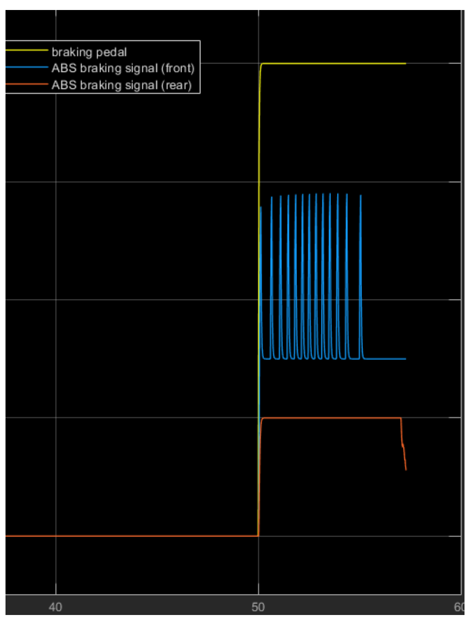

Figure 22: ABS output signals during emergency braking in wet conditions

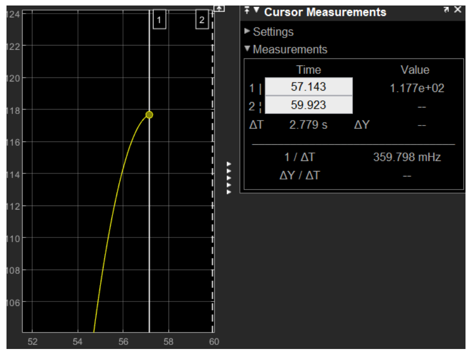

Figure 23: Stopping distance during emergency braking in wet conditions (ABS threshold at 0.12)

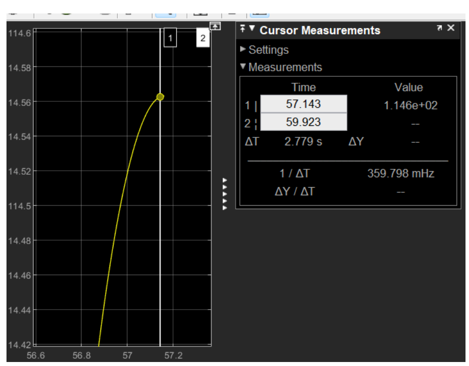

Figure 24: Stopping distance during simulation in wet conditions (ABS threshold at 0.09)