Report for the Course “Projektwettbewerb Konzepte der Regelungstechnik”

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Abstract: In this report, the result of ”Projektwettbewerb Konzepte der Regelungstechnik” is shown. The main task is to design a state-feedback controller, with which the simplified race car model can finish one lap as quick as possible. To achieve this target, a P-controller is implemented in this report. The time consumed is $t_f = 67.85s$. With Intel Core i7-6700HQ 2.6GHz, time consumption for simulation approximately is $t_{sim} = 3.2s$.

1. INTRODUCTION

The main task of project ”Projektwettbewerb Konzepte der Regelungstechnik” is to design a state-feedback controller, with which a single-track race car model can finish one lap of a given racing track as quick as possible, without getting out of the track boundary.
This simplified model consists of a state vector with ten states $x = [x, y, v, \beta, \psi, \omega, \dot{x}, \dot{y}, \dot{\psi}, \dot{\varphi}]^\top$ and an input vector $u = [\delta, G, F_b, \zeta, \phi]^\top$, namely the steering angle, gear stage, braking force, braking force distribution and the gas pedal.

2. MAIN IDEA

The design procedure was based on the idea that accelerating as much as we can in the straight lane and getting over the turning with the highest possible constant speed without side sliding, ideally.
In this report, our design procedure will be introduced in three aspects, the gear shift, speed control and steering wheel control.

2.1 Gear Stage Shift

This model has 5 possible gear stages, each has a different transmission ratio. Based on the idea that we want to accelerate in the straight lane as much as possible, we need to guarantee that the driving force, which is provided by the engine, on the tire to be maximized,

$$F_{driving} = \frac{1}{R} i(G) i_0 T_M(\phi, G) \quad (1)$$

where T_M is the motor torque, and it is heuristically given by

$$T_M(\phi, G) = 200\phi(15 - 14\phi)\left(1 - \frac{(\frac{30}{\pi} n(G))^{5\phi}}{4800^{5\phi}}\right) \quad (2)$$

$$n(G) = \frac{v i(G) i_0}{R}$$

Applying the formulations mentioned above, we can plot the maximum motor torque that can be achieved in different gear stages versus the race car’s velocity.

Through Figure 1, we can see that the gear needs shifting at each cross point when the velocity changes, so that the driving force can be maximized. The gear stages is then decided as described in the Table 1.

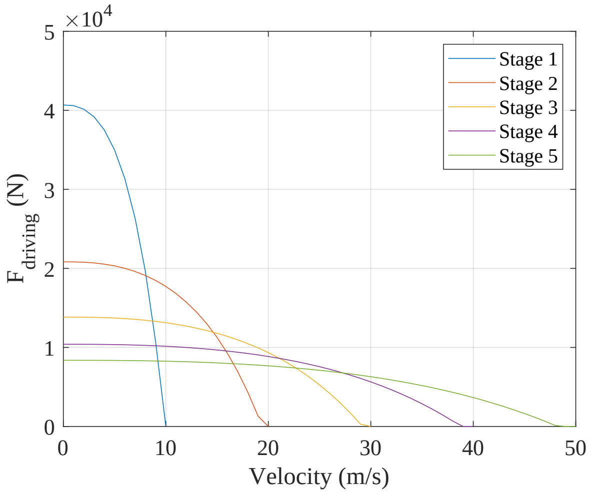

Fig. 1. Driving force $F_{driving}$ versus vehicle velocity v.

Table 1. Gear Stages.

Gear Stages G	**Velocity** $v(m/s)$
1	$[0, 8)$
2	$[8, 15)$
3	$[15, 21)$
4	$[21, 28)$
5	$[28, \infty)$

2.2 Speed Control

The idea of speed control is simple. In every phase of the lap, a reference velocity is given manually, if current velocity is below the reference velocity, then step on the gas pedal. If current velocity is higher than reference, then take brake. The reference can be seen in Table 2.

Table 2. Reference Velocity.

Phase G	**Reference Velocity** $v_{ref}(m/s)$
Straight lane	45
Turn #1	5
Turn #2	10.15
Turn #3	$\{18.9, 9.2\}$
Turn #4	$\{9.1, 10, 7, 8, 11.7, 9.5\}$

First, the control to the gas pedal need to be found. As defined in equation 2, the relation between motor torque and gas pedal is not linear, an optimal pedal position need to be found. We can find this position by setting the derivatives of T_M to be zero, then get the best pedal position ϕ^*. But after plotting driving force versus gas pedal position, we decide to use 0.6 as an approximation to the optimal position, because when $\phi = 0.6$, the drag forces in each gear stage are nearly maximized.

For braking, we didn't consider the brake force distribution, but only made the brake force to be maximum, so that the vehicle can slow down as soon as possible, which also means that we can have longer distance for high speed.

Finally, the time for braking should be determined. Here we introduced a detection index i_{det}, which is several indexes before our current index i_{cur}, which is the index of the closest point on the middle track line to our current real position.

The relation between i_{det} and i_{cur} is

$$i_{det} = i_{cur} + kv + 10 \tag{3}$$

where k is a factor that can be changed to adjust the detectable distance.

If at position i_{det} of the track, there is a turn, take brake to slow down and reach the corresponding reference velocity. The actual vehicle velocity and gear stage shifting can be seen in Figure 2 and Figure 3.

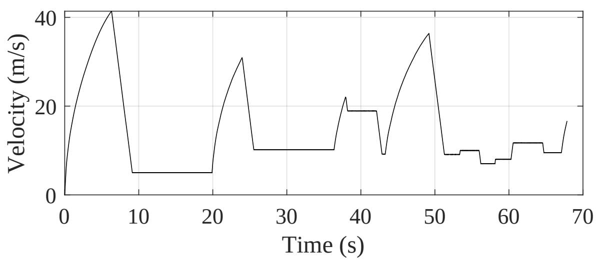

Fig. 2. Vehicle velocity v time t.

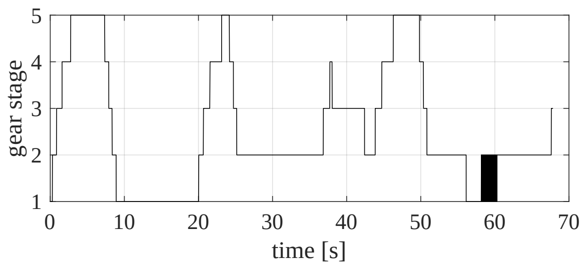

Fig. 3. Gear stage shifting G time t.

2.3 Steering Control

The basic thought of steering control is keeping the vehicle to the middle line of the track, or sometimes aiming at some specific target point during turning, so as to make a path with lowest curvature.

To implement this idea, a reference index i_{ref} is introduced, analog to detection index i_{det}, it is an index ahead of current index i_{cur}. As shown in Figure 4, the orientation of reference point with respect to the heading direction of vehicle is calculated, then a P-controller is applied to make θ_1 converges to 0, so as to control the car keep to the lane. Besides, we want the car's heading direction to be the same as the track's tangential direction, so we add another angle's difference θ_2 to the controller, with factor k_2. Then our controller can be formulated as following,

$$d\delta = k_1\theta_1 + k_2\theta_2 \tag{4}$$

$$\delta_{t+1} = \delta_t + d\delta \tag{5}$$

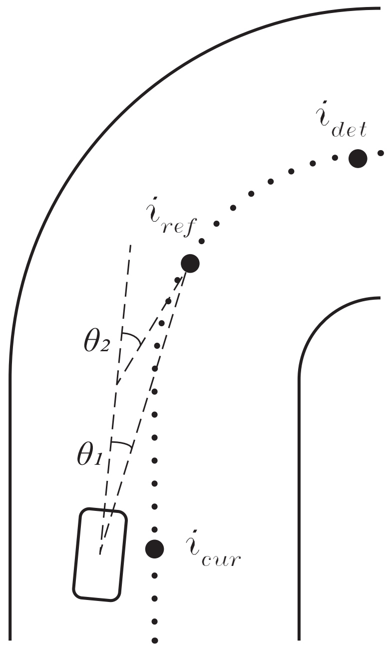

Fig. 4. θ_1 and θ_2 illustration of the reference point.

Considering the fact that the density of data points along the race track differs a lot, the distance that the i_{ref} ahead of i_{cur} varies, too. Typically large for turning, and small for straight lane. They are given manually for each phase of the race track.

What's more, for getting a better turning behaviour, a special reference index may be assigned manually when the vehicle prepares to enter a turn, as shown in Figure 5. It shows the behaviour of these three indexes from $t = 0$ to $t = 12s$. Before $t = 6s$ the green curve (i_{det}) grows faster than blue (i_{ref}) and red curves (i_{cur}) because the vehicle is accelerating, and i_{ref} leads i_{cur} a constant value.

After $t = 6s$, the vehicle detects a turn, and takes brake, making the detection index growing much slower. Then a constant reference index and reference position is assigned, that is the right side of the entrance of first turning, with which the vehicle can make a good turning behaviour. After $t = 9.5s$, the car is in the first turning. Due to the high point density, the difference of i_{ref} and i_{cur} is set to be larger than that of straight lane (difference between blue line and red line).

3. RESULT

Applying the controller described above, the simulation generates a lap time of $t_f = 67.85s$. Figure 6 shows the

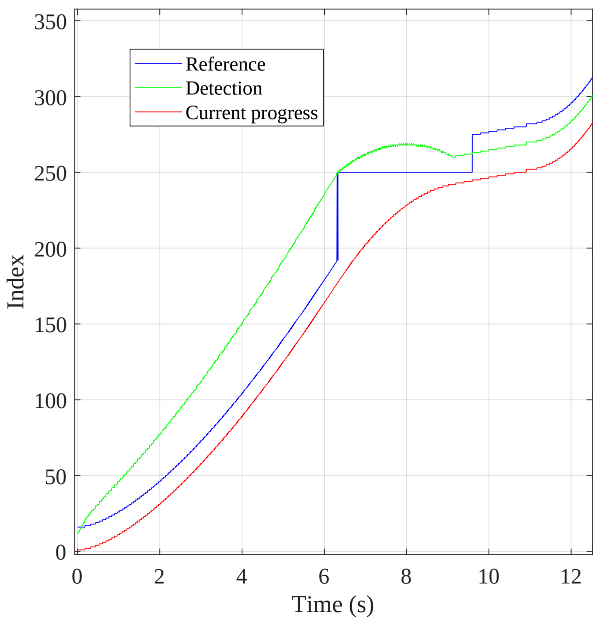

Fig. 5. Index versus time t from 0 to $12s$.

actual track generated by the race car. It can be seen that the car intends to drive through the turning with less curvature, so that a higher speed can be achieved. The simulation runs in a Windows laptop with Matlab R2020a and processor Core i7-6700HQ 2.6GHz, the approximated time consumption for one lap's simulation is $t_{sim} = 3.2s$.

REFERENCES

[1] Verschueren, R. (2014). Design and implementation of a time-optimal controller for model race cars. KU Leuven.

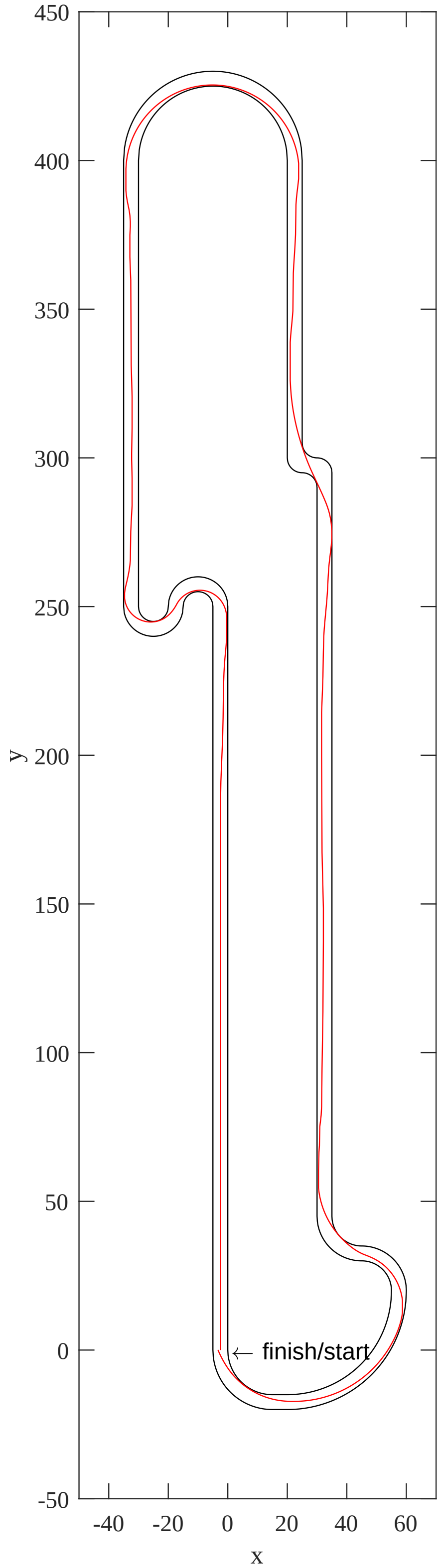

Fig. 6. Actual track generated by the race car for one lap.