Report for the Course "Projektwettbewerb Konzepte der Regelungstechnik"

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Abstract: In this report, the design of a controller for the "Projektwettbewerb Konzepte der Regelungstechnik" at the Institute for Systems Theory and Automatic Control, University of Stuttgart will be described. With this controller, a lap time of 67 seconds is achieved.

1. INTRODUCTION

The goal of this "Projektwettbewerb Konzepte der Regelungstechnik" is to design a state feedback controller for the single-track model in order to achieve a minimum lap time and not run out of the racetrack limits.

The single-track model's state equation can be written as

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{v} \\ \dot{\beta} \\ \dot{\psi} \\ \dot{\omega} \\ \ddot{x} \\ \ddot{y} \\ \ddot{\psi} \\ \ddot{\varphi} \end{bmatrix} = f\left(\begin{bmatrix} x \\ y \\ v \\ \beta \\ \psi \\ \omega \\ \dot{x} \\ \dot{y} \\ \dot{\psi} \\ \dot{\varphi} \end{bmatrix}, \begin{bmatrix} \delta \\ G \\ F_b \\ \zeta \\ \phi \end{bmatrix} \right) \tag{1}$$

the system consists of a state vector $[x, y, v, \beta, \psi, \omega, \dot{x}, \dot{y}, \dot{\psi}, \dot{\varphi}]^T$ and an input vector $[\delta, G, F_b, \zeta, \phi]^T$.

There are two main tasks: proper trajectory planning and controller design.

2. TRAJECTORY PLANNING

First a trajectory need to be constructed, so that the single-track model can drive along this trajectory under the control of the controller. According to the boundaries of the left and right sides of the racetrack, the midline of the racetrack can be chosen as the reference trajectory.

3. CONTROLLER DESIGN

3.1 Control of Steering Angle

The steering angle depends on the car's current yaw angle and the coming points on the trajectory. So a "looking forward controller" will be used to compute the suitable steering angle. Basically, the steering angle controller is a Proportional Controller, and has a simple form below:

$$\delta = K_{steer}\Delta\psi$$

The angle ψ between car's yaw angle and future direction of forward motion is computed with the cross product rule (2), and the future direction of forward direction points to a reference point on the trajectory. Firstly we should calculate the distance between all the points of trajectory and the car position (x, y), then pick the nearest point as the nearly car position, 20 points after that point can be seen as the reference point, which indicates the forward direction. The vector$\boldsymbol{b}$ from car positon (x, y) to the reference point is calculated directly in equation (3).

$$\theta = \arcsin\left(\frac{\boldsymbol{a} \times \boldsymbol{b}}{|\boldsymbol{a}| \cdot |\boldsymbol{b}|}\right) \tag{2}$$

$$\boldsymbol{a} = [\cos\psi, \sin\psi]$$
$$\boldsymbol{b} = [x - x_{ref}, y - y_{ref}] \tag{3}$$

And the proportional parameter K_{steer} is determined experimentally as 1.8.

3.2 Control of Velocity

To simplify the control task, the velocity v_{curve} of car on the curve should be kept constantly, and the velocities are computed with the normal acceleration a_n on the curve in equation (4), where the normal acceleration a_n is determined experimentally as 0.6 acceleration of gravity.

$$v_{curve_i} = \sqrt{R_i a_n} \tag{4}$$

According to the simulation, we optimized the speed of each curves on this basis, as shown in Table 1. The names of curve are showed in figure 1

Table 1. Reference speed for cornering

Curve	R_i **[m]**	v_{ref} **[m/s]**
1	10	6
2	15	12.5
3	5	5.3
4	10,35,15	6.5

On the straight, the car should accelerate with full throttle until it reaches the maximum speed, or when the car has already gone through the braking point before a curve, the car should brake with full braking force. Then the minimum lap time can be achieved.

Control of braking With the full braking force $F_b = 15000N$ we can make the car decelerate with the $a = 12.2m/s^2$(from simulation). And the distribution of braking force is simplified as a constant 0.5.

Control of gas pedal position The controller of the gas pedal position is also a two-point controller, when breaking, $\phi = 0$, when accelerating, $\phi = 0.7$. By simulation, when $\phi = 0.7$, the model accelerates faster, when it is equal to 1, the model accelerates slower due to the slippage of tyre.

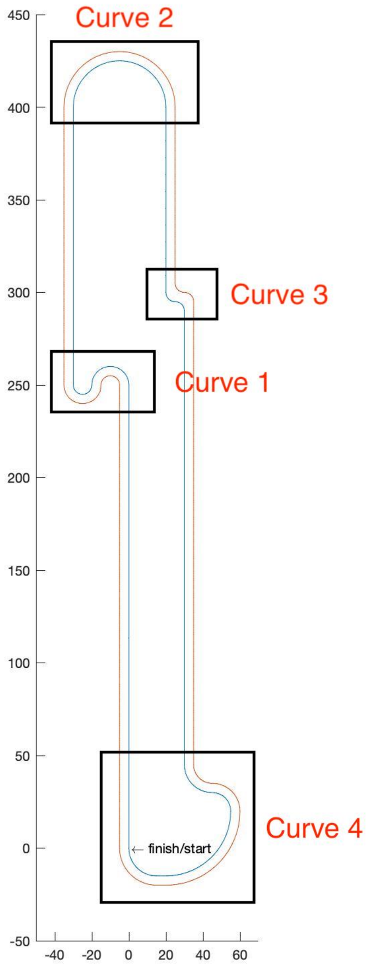

Fig. 1. Racetrack curve naming and division

Control of Gear transmission There are five gears in the single-track model. In order to allow the model to obtain a relative larger acceleration, the gear transmission controller should be designed, so that the gear will be switched automatically when the model is in a different speed. The controller is shown as

$$G = 1 + \lfloor \frac{v}{\alpha} \rfloor, \alpha = 8 \tag{5}$$

Through simulation, the maximum speed that the model can achieve on this racetrack is about $45m/s$. Then to make the model accelerate faster while keeping the output G of the controller no more than 5, the coefficient $\alpha = 8$ is chosen and a judgment statement is added to the gear transmission controller.

4. RESULTS

Implementation of the controller described above yields a lap time of $t_f = 67s$ for the chosen parameters.

The figure 2 shows the resulting driven path and the figure 3 shows the resulting velocity curve of the model.

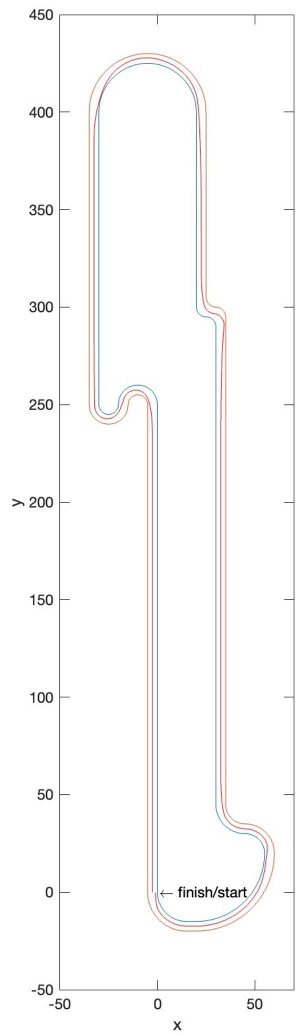

Fig. 2. The final resulting path

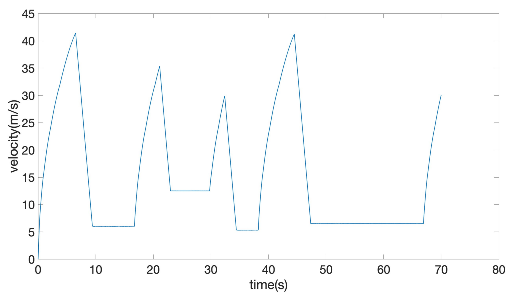

Fig. 3. The resulting velocity