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Race driver model

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Abstract

The best race driver is the one that, with a given vehicle, is able to drive on a given track in the shortest possible time. Thus, the only target is the lap time. A race driver model has to do the same.

The first step towards this target is to decide which trajectory to follow. In fact, the optimal trajectory is the best compromise between the shortest track and the track that allows to achieve the highest speeds (least curvature track). Thus, the problem of trajectory planning is a bounded optimisation problem that has to take into account not only the geometry of the circuit but also the dynamics of the vehicle. A simplified vehicle dynamic model is used for this purpose. Due to the fact that the vehicle will be driven at its limit performances, although simplified, the model has to correctly reproduce the maximum possible acceleration, a function of the vehicle speed, the maximum possible deceleration, again a function of the vehicle speed, and the maximum lateral acceleration, a function of both the vehicle speed and the steering angle. Knowing the trajectory, the vehicle model allows to determine the lap time. Through an optimisation algorithm it is therefore possible to determine the best compromise between shortest track and track with the minimum curvature, i.e. the trajectory (in terms of track and speed profile) that allows to minimize the time lap.

Once the best trajectory has been determined (both in terms of best track and best speed profile), it is necessary to identify the driver's inputs to follow the given trajectory. This task is carried out by considering the driver as a controller that acts on a nonlinear plant (the vehicle) in order to achieve the desired results. Thus, the driver converts the best trajectory into vehicle's inputs. The mutual interaction between plant and controller (the driver's inputs are not only a function of the best trajectory but also of the driver's reactions due to the vehicle's dynamics) is not taken into account in this paper.

Keywords: Race driver; Numerical model; Trajectory planning; Driver's inputs

1. Introduction

A race driver should be able to push a racing car at its highest performance exploiting all the friction forces developed at the tire–road interface according to the constraints imposed by the handling characteristics of the vehicle and by the available traction/braking power.

A mathematical model of a race driver represents an important tool for the development of a race car at a design stage since it actually could provide information about the effective potential of a racing car, drawing guidelines for the trade-off among different solutions. Moreover cost benefits could be achieved since expensive activities such as set-up definition (adjustment of suspensions' parameters, anti-roll bar tuning, settings of aerodynamics devices) could be partially carried out in a virtual environment. Thus, a driver model might also be useful to identify the optimal vehicle set-up to obtain the best lap time on a determined circuit with an assigned racing car.

The first step to design a race driver model is represented by trajectory planning, i.e. the definition of the optimal trajectory that allows to obtain the lowest lap time. This problem has been investigated by several authors [1–4] focusing the attention on car-like robots. Unfortunately in many cases the trajectory planning is considered a purely geometrical problem, regardless of the vehicle's dynamics. Instead, the optimal trajectory is the best compromise between the shortest track and the track that allows to achieve the

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highest speeds (least curvature track). What determines the weight between these two solutions is the vehicle's dynamic behaviour. As an example, a least curvature trajectory allows higher speeds, but if the engine does not provide enough power to reach such speeds, a shorter trajectory should be preferred.

Once the optimal trajectory and speed profile have been determined, it is necessary to convert them into driver's inputs. This is done by considering the driver as a controller that has the possibility to change some vehicle's inputs (gear, clutch, brake, accelerator and steer wheel angle) in order to follow the planned trajectory [5]. It can be clearly seen that these inputs have to take into account the dynamics of the vehicle.

It should be considered that, for a real driver, inputs are not only a function of the planned trajectory but also of the vehicle's dynamics that, as already said, is a function of these inputs. Thus, a third layer has to be added to the trajectory planning phase and the identification of driver's inputs phase, i.e. the optimisation of driver's inputs phase. This third layer allows to further optimise the lap time, by taking into account both the vehicle performances and the driver's reactions, and to achieve a driver's behaviour that is very similar to real one [6].

2. Trajectory planning

The goal of a race driver can be easily described: minimize the lap time. Two strategies can be followed to reach this task: minimize the space and/or maximize the speed. The maximum speed $v_{\max}$ achievable while negotiating a curve of radius ρ is limited by the maximum centripetal force developed by the tires which can be estimated as follows:

$$ma_{y,\max} = m\frac{v_{\max}^2}{\rho} = \mu(mg + F_{\mathrm{a}});$$
$$\Rightarrow \quad v_{\max} = \sqrt{\mu\rho\left(g + \frac{F_{\mathrm{a}}}{m}\right)} \tag{1}$$

In (1) m represents the vehicle's mass, μ the tire–road friction coefficient, F_{a} the aerodynamic downforce. Relation (1) shows that the two strategies of space minimization and speed maximization are conflicting: the shortest path approach leads to a trajectory characterized by low curvature radii while the highest speed approach pushes towards high curvature radii (i.e. the minimization of curvature).

Fig. 1 should clarify the situation: the minimum space trajectory (a) presents the lowest curvature radius; trajectory (b) is characterized by the largest curvature radius (minimum curvature) and allows to negotiate the curve at the maximum speed, but presents a sensible increase of space. The solution that leads to the lowest lap time is a compromise between trajectory (a) and (b) and is strictly dependent on the vehicle's dynamics. The tire–road adhesion condition might make it impossible to follow trajectory (a) except at very low speeds. At the same time, the engine might not be able to produce the required driving torque and thus the speed allowed by trajectory (b).

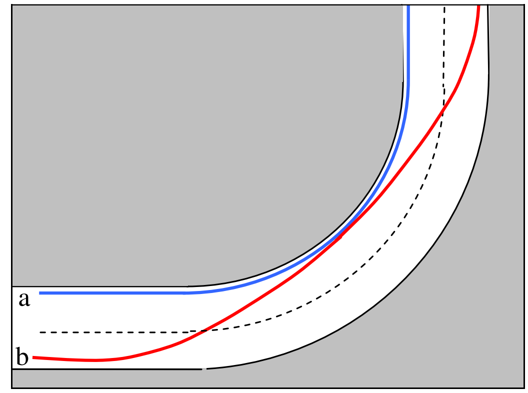

Fig. 1. Comparison between shortest space (a) and lowest curvature (b) trajectories.

According to the approach followed in this work, at first the pure geometrical problem is analyzed. Algorithms are developed to identify the shortest path and the trajectory with the lowest curvature given the track centerline trajectory and the road width. Then, a simplified vehicle model is used to identify the most appropriate weights for the two solutions thus allowing to determine the optimal path and the corresponding speed profile.

3. Geometrical problem

Both the algorithms developed to identify the shortest path and the trajectory with the lowest curvature solve a constrained minimization problem since the identified solution has always to be inside the track. The algorithms are based on a discretization of the track into several segments, as shown in Fig. 2.

At the end of each segment the position of a given point on the track is identified using the following equation:

$$\begin{aligned}\vec{\mathbf{P}}_i &= x_i\vec{\mathbf{i}} + y_i\vec{\mathbf{j}} \\ &= [x_{r,i} + \alpha_i(x_{l,i} - x_{r,i})]\vec{\mathbf{i}} + [y_{r,i} + \alpha_i(y_{l,i} - y_{r,i})]\vec{\mathbf{j}} \\ &= [x_{r,i} + \alpha_i\Delta x_i]\vec{\mathbf{i}} + [y_{r,i} + \alpha_i\Delta y_i]\vec{\mathbf{j}}\end{aligned} \tag{2}$$

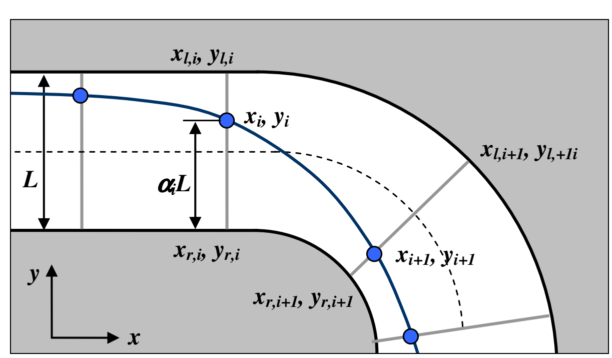

Fig. 2. Trajectory discretization.