Control and simulation for a driverless racing vehicle

Summary
The goal of this project is to control a driverless vehicle around a known circuit given its multiple constraints. An important part of the development is also done through simulation, which is why a simulation and data analysis framework should also be set up during this project.

Hardware

- Motor under the front axle used as a steering actuator. This motor is able to steer from full left to full right in less than 0.9s.
- Emergency Braking System (EBS) installed behind the pedals. It can be triggered from either a Remote Emergency System (RES) or from an on-board computer.
- As the car is electric and will be equipped with a regenerative braking system, we don’t need any controls on the pedals.

Control

After the first successfully finished lap, the complete track is mapped using the SLAM algorithm. Thus, the car now knows the track layout and can localize itself within the environment. Given this capability, we can race the car around a known track. Which brings us to our motion planning problem where the goal is to drive around the track as fast as possible. We optimize the racing path with the minimum curvature using an elastic beam optimization algorithm and then we use a predictive model controller (MPC) to calculate the optimal trajectory.

1. **Vehicle model**
    a. **Dynamic bicycle model**
    The task of driving a vehicle at its operational limits is challenging due to the highly nonlinear behavior in this operation range. Therefore, the dynamics of the racecar should be modeled after the dynamic bicycle model with nonlinear tire force laws. The model is able to match the performance of the car even in racing conditions, while at the same time being simple enough to allow the MPC problem to be solved in real-time.
    b. **Tyre constraints**
    One of the assumptions in the dynamic bicycle model, is that the combined slip can be neglected. Combined slip occurs if the tire has to transform lateral as well as longitudinal forces. In such a case a real tire cannot produce the same maximum grip as in pure conditions. Simply said, a tire has a certain elliptic force budget it can transfer to the ground, often called the friction ellipse. This budget can be introduced as a constraint without explicitly modeling combined slip, which would require additional states.
2. **Planning**
    a. **Contouring formulation**
    The goal of the contouring formulation is to follow a reference path as fast as possible, in our case the center line of a track parametrized by the arc length.

A third order spline is used to describe the path, as it offers a fast way to evaluate any point along the contour. To follow the path, the position of the car has to be linked to the position on the path, or in other words the arc-length.

b. **Track constraints**
Finally, we consider track constraints, which limit the MPC to stay within the track boundaries. The constraint is formulated by locally approximating the track by circles centered on the middle line.

3. **MPC problem estimation**
In summary, the dynamics of the problem are given by the vehicle model, the input dynamics, and the arc-length dynamics.

Simulation

Real-world testing with the racecar requires time and manpower that drastically limits the number of tests that can be performed. Simulation is used to catch problems before they happen on the race track and thus increase the efficiency of the actual testing.
The simulated race track surface is approximated as a flat plane with constant friction. Perception sensors are not simulated because of large computational requirements. Instead, direct cone observations with various noise models are simulated. Simulation results are post processed to give a binary pass/fail and further lap statistics, i.e. lap times. Logged data is uploaded to a data analysis system and immediately processed into a set of visualizations. In case of a failure, notifications are sent out. This reduces the iteration time and increases the software quality.

Software:

- https://gitlab.com/eufs/eufs_sim
- https://github.com/AMZ-Driverless

Sources

https://arxiv.org/pdf/1905.05150.pdf
https://arxiv.org/pdf/2007.13971.pdf
http://www.imgeorgiev.com/2020-06-19-formula-student/