Racing Line Optimization with Adaptive Grip Estimation

Problem:
Motor racing is a sport highly sensitive to conditions. The limit of the vehicle can vary depending on the weather, track temperature, tire pressure and so on. In order to get to optimal speed, adapting to changing environment is necessary.

Goal:
- Learn changing conditions by estimating tire grip.
- Adapt to conditions while minimizing the risk of losing traction.
- Optimize racing line based on current conditions and track.

What is Indy Autonomous Challenge?

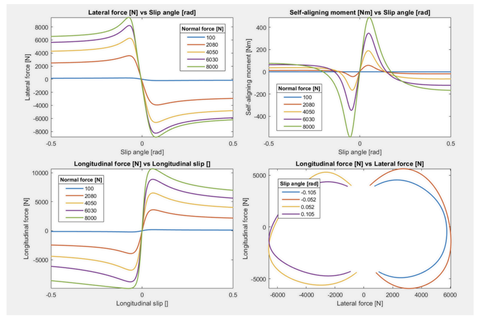
The Indy Autonomous Challenge gathers university teams from around the world to compete in a series of challenges to advance technology that can speed the commercialization of fully autonomous vehicles and deployments of advanced driver-assistance systems (ADAS) to increase safety and performance. The competitions are a platform for students to excel in Science, Technology, Engineering, and Math (STEM).

Tire Modeling / Grip Estimation

What is Magic formula?
The Magic Formula is a mathematical model used to describe the complex relationship between tire forces (like lateral, longitudinal, or aligning torque) and slip (slip angle or slip ratio) in vehicle dynamics.

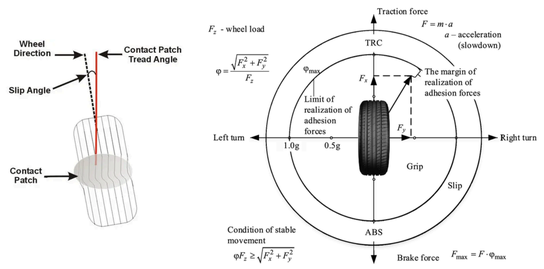
Our Methods:
General tire parameters were given by Firestone. We created our tire model based on these parameters.
Tire modeling and grip estimation will be our methods to learn about environments and track conditions.

CPI tire modeling



- Extension of Magic formula.
- Able to calculate contact patch based on deformation and pressure.
- Consider slip angle and slip ratio for lateral and longitudinal force calculation.

Grip estimation

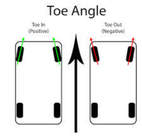


- With suspension analysis data, we can calculate camber and slip angle from suspension movement.
- Use slip angle to gauge amount of grip used.
- Normalize this data to find more optimal racing line.

Suspension Research/Findings

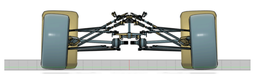
In order to accurately estimate tire grip, understanding the suspension structure of our model is key. From this suspension analysis, we can generate useful data for tire grip estimation and racing line optimization.

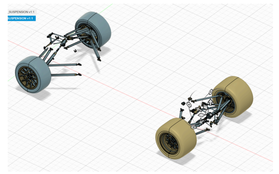
Why is it important to understand toe and camber?
Toe and camber are important to understand because they play a large role in how much grip our tires will get depending on the circumstances. They help us know what strategies to use depending on the situation by giving us an idea of how much grip we are going to have.



Camber: Angle that the tires make with respect to the ground from a head-on perspective, which can change the amount of area of the tire that is in contact with the track.
Toe: Angle that the front or back tires make with respect to the longitudinal axis, which affects friction, acceleration, and slip angle.

Our methods:
By using various CAD software, we were able to analyze our vehicle's suspension model and determine its camber and toe. Our CAD software also allows us to run motion simulation that can determine how our suspension model will fare under applied forces.





Notice how this car's front-left tire is tilted inward to give a better grip. This is the proper use of negative camber.

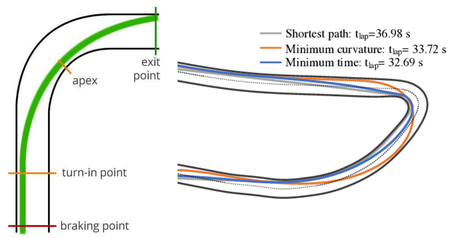
The drift lines indicate that drifting on corners is indeed one way to take advantage of our camber.

The blue car did not take the corner hard enough, so the wheels didn't properly align for maximum grip. Because of this, it spun out.

Racing Line Optimization (In progress)

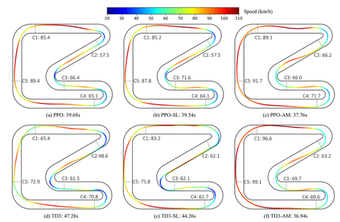
Our Methods:
We are planning on using a sampling-based racing line optimization algorithm where we use previous laps' grip estimation to determine the best racing line. This method will lead to robust racing line optimization for changing environments.

Sampling Strategy



- Starts from pre-calculated racing line.
- Exploration behavior will be needed to generate tire data.
- Sample 3 points, Turn in, Apex, and Exit.
- Generate curve by setting Apex to max curvature, slowly decrease curvature as line goes to turn in or exit

Racing Line calculation



- Estimate suspension movement based on the speed and acceleration to get camber and toe.
- Based on camber angle, speed, and current tire pressure, find maximum speed for each corner.
- Choose path with highest average value.
- Normalize grip data to get characteristic of the track. Effect of banking, elevation change, etc.

Future plans
- Further simulations on suspension to estimate camber on given speed and curvature.
- Finish racing line optimization algorithm and run test on previous data.
- Visualize normalized tire grip to show characteristic of the track.
- Lastly, test algorithm on real race car.