Answers to General Questions

Why is autonomous racing challenging?

Autonomous racing is challenging because it requires operating at the physical, computational, and algorithmic limits of the vehicle. It involves high-speed dynamics, real-time decision-making, and the necessity for reliability, especially when operating at the friction limit (e.g., in high-speed or low-friction environments). Additionally, it demands a full autonomy stack that includes perception, planning, and control, all of which must perform robustly under extreme conditions.

What is meant by infrastructure-less localization?

Infrastructure-less localization refers to the ability of the autonomous system to localize itself without relying on external infrastructure such as GPS or motion capture systems. Instead, it uses onboard sensors (e.g., LiDAR, IMU) and algorithms (e.g., SLAM or MCL) to determine its position within a predefined environment.

Frenet Coordinates

Explain Frenet coordinates.

Frenet coordinates are a curvilinear coordinate system defined relative to a reference path (e.g., a racing line). A point in Frenet coordinates is represented as (s, d), where {s} denotes the progression along the reference path, and {d} represents the orthogonal distance from the path. The {s} coordinate is cyclical (wrapping upon completing a lap), and {d} is negative to the right of the path and positive to the left.

Mention the advantage of using Frenet coordinates.

The advantages of using Frenet coordinates include:

- Simplifying tasks such as determining a point's position relative to the racetrack.
- Facilitating the description of motion models relative to the reference path.
- Easing the generation of evasion waypoints that align with the racing line.
- Benefiting any computation involving spatial coordinates relative to the racing line.

State Estimation

What is the role of the IMU?

The IMU (Inertial Measurement Unit) tracks the racecar's orientation and motion by analyzing rotational and linear movements using an accelerometer and a gyroscope. It provides 6-DoF data (orientation and acceleration) at 50 Hz, which is fused with wheel odometry in the state estimation process to improve velocity estimates, especially in cases of tire slip.

Explain the used state estimation method.

The state estimation method involves two main parts:

1. Odometry Filter: An Extended Kalman Filter (EKF) fuses wheel odometry (from VESC) and IMU data to estimate longitudinal and lateral velocities, and yaw rate.
2. Localization: Two mutually exclusive methods are used:
    - Cartographer: A pose-graph SLAM method for accurate and smooth pose estimates under good odometry conditions.
    - SynPF: A particle filter-based method robust to wheel slip and low-quality odometry.

    The final state aggregates the localization pose and velocity estimate.

Perception

What features are extracted from LiDAR detections?

From LiDAR detections, the following features are extracted after clustering and filtering:
Size of the obstacle (number of points or physical dimensions).
Center coordinates of the approximated rectangle.
Rotation of the rectangle.
These features are used for obstacle classification and tracking.

Why was an opponent tracking module added?

The opponent tracking module was added to provide continuous estimation of the opponent's position and velocity, even when the opponent is out of line of sight (e.g., behind a curve). This ensures safe and efficient maneuvering, prevents unnecessary braking, and avoids collisions due to misjudgment of the opponent's position.

Motion Planning and Control

What is the purpose of the local planner?

The local planner generates a feasible and performant trajectory to avoid obstacles and execute overtaking maneuvers during head-to-head racing. It uses the global racing line as a reference and creates a spline-based path around detected opponents, ensuring the vehicle can react dynamically to environmental changes.

What are the roles of the lateral and longitudinal controllers?

- Longitudinal Controller: Computes the desired velocity of the racecar. It either tracks the velocity profile from the planned trajectory (nominal control) or maintains a safe distance to a leading opponent (trailing control).
- Lateral Controller: Computes the steering angle to accurately follow the spatial trajectory. It uses the Model- and Acceleration-based Pursuit (MAP) controller, which incorporates tire slip for improved tracking performance at high speeds.