Reinforcement Learning for Interactive Overtaking in Autonomous Racing

Hemanth Raj Tekumalla, Varun Reddy Patlolla

CS 4180/5180 – Reinforcement Learning and Sequential Decision Making (Spring 2025)
Northeastern University

1 Problem Description

1.1 Introduction

Autonomous racing requires intelligent agents to make **real-time overtaking decisions** while ensuring safety and minimizing lap time. Traditional rule-based trajectory planning methods **fail to adapt dynamically** to interactive opponents. In this project we will work on a **Multi-Agent Reinforcement Learning (MARL) system** that enables autonomous race cars to:

- Predict and react to opponent behavior.
- Plan overtaking maneuvers dynamically.
- Execute safe overtakes while optimizing lap time.

1.2 Environment Setup for RL

The F1TENTH simulator will serve as the environment for testing RL-based overtaking strategies. The RL framework will be structured as follows:

State Space:
- Vehicle position, velocity, and heading.
- Distance to track boundaries and opponent vehicles.

Action Space:
- Steering control.
- Acceleration and braking.

Reward Function:
- Positive rewards for successful overtakes and lap completion.
- Heavy Penalty for **collisions** or going off-track.
- Negative rewards for each time step to encourage faster lap times.

2 Objective

The RL agent will learn an optimal overtaking policy that balances speed, safety, and efficiency. We will implement compare PPO and MADDPG to determine which reinforcement learning method is more effective for interactive autonomous racing.

3 Algorithms to be Used

To evaluate different RL strategies, we will try to implement:

Algorithm	Type	Purpose
PPO	Single-Agent RL	Baseline for continuous control in racing.
MADDPG	Multi-Agent RL	Enables cooperative and competitive multi-agent behaviors.

Table 1: Reinforcement Learning Algorithms for Overtaking

4 Expected Results

4.1 Policy Convergence

Using model-free RL, the agent is expected to converge to an **optimal overtaking policy** that maximizes overtaking success rates with faster lap times and minimizes collision risk.

4.2 Performance Metrics

Evaluation criteria include:

- **Lap Time Reduction** – Faster completion of the race with strategic overtaking.
- **Overtaking Success Rate** – Percentage of clean overtakes without collisions.
- **Safety Score** – Reduction in crash occurrences.

4.3 Optimal Policy Parameters

The policy parameters θ^* will be iteratively optimized using RL to maximize the cumulative reward:

$$\theta^* = \arg\max_{\theta} E[R_T|\theta]$$

where R_T represents the total reward over the racing episode.

5 Project Timeline

Week	Task
1	Setup F1TENTH simulator and implement rule-based racing baseline.
2	Implement PPO and MADDPG algorithms for interactive overtaking in autonomous racing.
3	Conduct comparative evaluations on success rate, lap time, and safety.
4	Finalize project report, summarize results, and suggest improvements.

Table 2: Project Timeline (4 Weeks)

6 References

- F1TENTH Autonomous Racing Platform
- RL-Based Overtaking Strategies for Autonomous Racing