Algorithmic Robot Motion Planning Project Proposal

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Abstract

In this work, we will investigate the application and optimization of popular motion planning algorithms such as RRT and RRT* for an autonomous small-scale competitive racecar being developed under the F1Tenth framework. The aim of the work is the successful implementation of two such algorithms both in simulation (provided by the University of Pennsylvania) and on the physical car (also provided by UPenn), along with an investigation into techniques that will guarantee minimal lap time for an initially unknown racetrack.

Figure 1: Stock photo of an F1Tenth car

Introduction

F1Tenth is an international community of researchers, engineers, and autonomous systems enthusiasts founded at the University of Pennsylvania in 2016. F1Tenth's mission is to provide an open-source platform for autonomous systems research and education, along with holding a number of autonomous race car competitions each year where teams from all around the world gather to compete.

The Technion F1Tenth Team was established in July 2022 and launched in October 2022, with 4 team members across 4 faculties receiving guidance from Dr. Kiril Solovey of the Technion's Electrical & Computer Engineering Faculty. The team currently has one F1Tenth car ready, and is in the process of building four more. Their current goal is to race their car at the 11th edition of the F1Tenth Grand Prix competition, being held at ICRA 2023 in London in late May. As part of the project, they are aiming to implement advanced motion planning algorithms on the car in order to ensure its optimal performance at the competition, where it will need to race around a previously unknown racetrack in the shortest amount of time possible.

Project Description

As part of the final project for the "Algorithmic Robot Motion Planning" course, the aim of the author will be to implement at least two motion planning algorithms on the racecar, both in simulation and on the physical car. The car uses a Hokuyo UST-10LX planar LiDAR sensor in order to detect obstacles and build a 2D map of the racetrack (using SLAM methods, to be implemented by us), and with this information we will run algorithms like RRT as local planners to lead the car through the track in the shortest amount of time possible.

The simulation for this project has already been built by the University of Pennsylvania, and it is written using ROS2 Foxy (which will be the main distribution used throughout this project) with a single track (bicycle) model from the Technical University of Munich's CommonRoad software package to simulate a rear wheel drive car with Ackermann steering. The simulation uses RViz for visualization, and its GUI appears as follows:

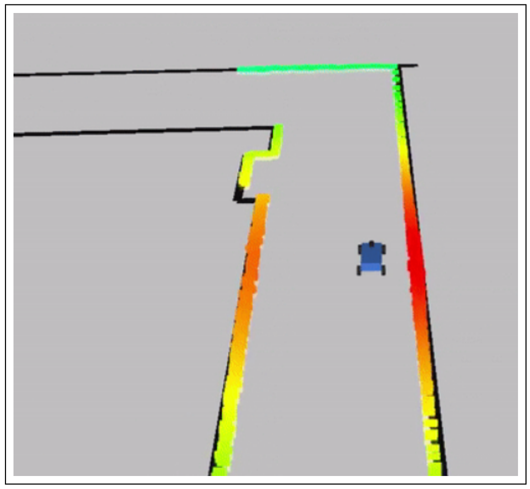

Figure 2: Screenshot from the F1Tenth simulator, prepared by UPenn

The blue box represents the car itself, the grey background represents free space, the black lines mark the boundaries of the racetrack, and the colorful points along the boundaries represent LiDAR data received by the car. The first part of the project will involve the use of this simulator (and custom Python packages in ROS2 Foxy) in order to implement the motion planning algorithms in question, and to begin to get an understanding for optimization tactics that we can use to improve their performance. This will mark the primary research phase of the project, in which parameters like re-planning rate, maximum velocity, step size, and goal bias are all investigated and optimized in order to ensure the minimal average lap time for the car over the course of 10 laps on a known and an unknown racetrack.

The latter part of the project will involve the implementation of these algorithms on the physical car, which was kindly lent to the Technion team by the UPenn F1Tenth team. The F1Tenth Simulator was carefully designed so that code written for the simulator should be easily transferred to the physical car, and so this transition should hopefully be a straightforward one. Once the algorithms are successfully implemented on the car, the secondary research phase of the project will begin. This phase has similar aims as the primary one, only this time the testing will be conducted on the physical model.

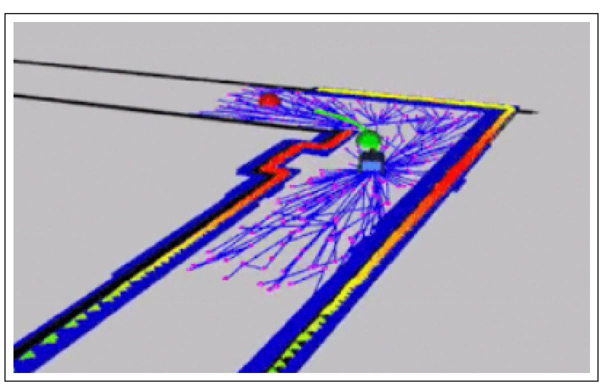

Figure 3: Screenshot from the simulator showing the implementation of the RRT algorithm for local planning (from UPenn)

Grading Structure

The bare minimum necessary for this project to be assigned a passing grade (85+) is the successful implementation of one motion planning algorithm in the F1Tenth Simulator, with a basic analysis provided. A moderately successful project (90+) will include the successful implementation of two motion planning algorithms in the simulator, with a deep analysis of their head-to-head performance and optimization tactics for each.

A greatly successful project (95+) will include the successful implementation of two motion planning algorithms both in the simulator and on the physical car, with a deep analysis of their head-to-head performance and optimization tactics for each. To receive full marks for the project (100), the author must do all of the above, and send Oren and Dean a cool video of the racecar zooming around a (hopefully non-trivial) racetrack using motion planning algorithms (maybe we will be able to throw some boxes at it or something while it drives to see if it's able to do dynamic obstacle avoidance - if we do the local planning well enough this shouldn't be too much of a problem).

Project Timeline

Week 1: January 1st to January 7th

- Car lent by UPenn arrives in Israel [DONE]
- Manual control of the car is successfully conducted [DONE]
- Simple algorithms for reactive control are implemented in the simulation, such as wall-following, automatic emergency braking (AEB), and follow-the-gap [DONE]

Week 2: January 8th to January 14th

- Autonomous control of the car is attempted, using the simplest algorithms (i.e. wall-following)
- The first motion planning algorithm is being developed and tested by the simulator
- Materials to build a racetrack are obtained, and the first simple racetrack is constructed in CRML [DONE]

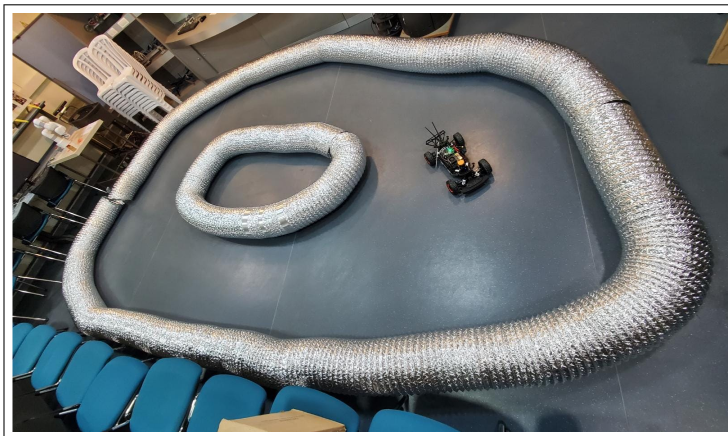

Figure 4: The first racetrack built by the Technion team, in CRML using collapsible aluminum ventilation ducts

Week 3: January 15th to January 21st

- The car is able to successfully complete 1 lap around the racetrack autonomously
- The car's SLAM capabilities are investigated (simulation and physical car)

- The first motion planning algorithm is successfully tested in the simulator, and is now being tested on the physical car

Week 4: January 22nd to January 28th (Last Week of Classes)

- The car is able to successfully complete at least 1 lap around the racetrack autonomously
- The car's SLAM capabilities are confirmed on the physical car
- The second motion planning algorithm is being developed and tested by the simulator; progress on the first one (on the physical car) continues

Weeks 5-7: January 29th to February 18th (Moed Aleph Exams)

- Progress on the project expectedly slows down due to the advent of Moed Aleph exams
- First exam: February 1st
- Last exam: February 15th
- Strong pace picks up from the 15th onward

Week 8: February 19th to February 25th

- Break period between Moed Aleph and Moed Bet exams $\rightarrow$ full steam ahead on the project
- The first motion planning algorithm is successfully tested on the physical car
- The second motion planning algorithm is successfully tested in the simulator, and is now being tested on the physical car
- Research phase begins and strong progress is achieved, final report starts to get drafted

Week 9: February 26th to March 18th

- Progress on the project expectedly slows down due to the advent of Moed Bet exams
- First exam: March 1st
- Last exam: March 15th
- Pace picks up from the 15th onward
- Steady, slow progress during exams, followed by strong pace towards the finish line once exams end - the final report undergoes its first and second drafts

Week 10: March 19th to March 21st (Final Week of the Project)

- The research phase is completed, and the finishing touches are put on the report
- The report is submitted by March 21st (the first day of the Spring semester)
- Oren and Dean receive a cool video of the physical car using motion planning methods like those we learned in class to autonomously complete multiple laps around an unknown racetrack

Week _: May 29th to June 2nd (ICRA 2023 & London F1Tenth Grand Prix)

- Participation in the 11th edition of the F1Tenth Grand Prix competition, being held at ICRA 2023 in London
- The Technion team obliterate the opposition and take home the gold, all thanks to their algorithmic prowess and intimate knowledge of motion planning algorithms