Czech Technical University in Prague
Faculty of Electrical Engineering
Department of Control Engineering

Localization and advanced control for autonomous model cars

Master's thesis

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Master programme: Cybernetics and Robotics
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MASTER'S THESIS ASSIGNMENT

I. Personal and study details

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Study program: **Cybernetics and Robotics**

Branch of study: **Cybernetics and Robotics**

II. Master's thesis details

Master's thesis title in English:

Localization and advanced control for autonomous model cars

Master's thesis title in Czech:

Lokalizace a pokročilé řízení autonomního modelu vozidla

Guidelines:

1. Make yourself with F1/10 competition, ROS project and software that was used in previous competitions.
2. Review possibilities of using advanced methods for vehicle time-optimal control.
3. Implement an algorithm for vehicle localization on the track. Reliable solution will probably need to fuse results of multiple localization methods.
4. Implement an algorithm for vehicle time-optimal control on the race track using the developed localization algorithm.
5. Properly test and document the results.

Bibliography / sources:

[1] F1/10 – The Rules version 1.0, http://f1tenth.org/misc-docs/rules.pdf
[2] Jan Filip, Sledování trajektorie pro autonomní vozidla, diplomová práce ČVUT, 2018

Name and workplace of master's thesis supervisor:

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Name and workplace of second master's thesis supervisor or consultant:

Date of master's thesis assignment: **01.02.2019** Deadline for master's thesis submission: **24.05.2019**

Assignment valid until:
by the end of summer semester 2019/2020

Ing. Michal Sojka, Ph.D.	prof. Ing. Michael Šebek, DrSc.	prof. Ing. Pavel Ripka, CSc.
Supervisor's signature	Head of department's signature	Dean's signature

III. Assignment receipt

The student acknowledges that the master's thesis is an individual work. The student must produce his thesis without the assistance of others, with the exception of provided consultations. Within the master's thesis, the author must state the names of consultants and include a list of references.

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Date of assignment receipt Student's signature

Declaration

I hereby declare I have written this master's thesis independently and quoted all the sources of information used in accordance with methodological instructions on ethical principles for writing an academic thesis. Moreover, I state that this thesis has neither been submitted nor accepted for any other degree.

In Prague, May 2019

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Bc. David Kopecky

Abstract

The goal of this thesis is to develop a solution for F1/10 autonomous driving competition. First part of the work deals with mapping and vehicle localization on the racing track with a down-scaled model car. Introduced localization use the Monte Carlo methods to process the data from LiDAR and estimate the position of the vehicle. The implemented system is able to precisely estimate the vehicle position with the rate of 25 Hz. The second part of the thesis deals with the design of the trajectory tracking control system. The presented solution uses the LQR and Model predictive control to achieve good performance with knowledge of vehicle kinematics.

Keywords: F1/10 competition, Autonomous racing, Monte Carlo Localization, Hector SLAM, trajectory tracking, Model Predictive Control

Abstrakt

Tato prace se zabyva mapovaním a lokalizací na zavodní draze F1/10 autonomous driving competition pomocí zmenseneho modelu vozidla. Lokalizace vyuzíva Monte Carlo metod pro zpracovaní dat LiDARu a odhad pozice vozidla. Implementovany system dokaze kvalitne odhadovat pozici s frekvencí 25 Hz. Druhou častí prace je navrh rídicího systemu sledovaní trajektorie. Navrzeny system vyuzíva pokrocilych metod rízení LQR, Model Predictive Control a uvazuje kinematicky model rízeneho vozidla.

Klícova slova: F1/10 competition, Autonomní rízení, Monte Carlo lokalizace, Hector SLAM, Sledovaní trajektorie, Model Predictive Control

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Finally, I must express my very profound gratitude to my parents for providing me with unfailing support and continuous encouragement throughout my years of study. This accomplishment would not have been possible without them.

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Chapter 1

Introduction

The goal of this thesis is to develop a control system able to race with a vehicle model scaled by 1/10 on the racing track with the utilization of high-level planning on the created map. The task is divided into three major parts. The objective of the first part is to develop a mapping system, which use the sensor data to explore the unknown environment and create a map of the track. The second part deals with the vehicle localization on the track without an absolute position sensor such as GPS or any indoor localization. The third part then aims to a lateral control system which drives the vehicle over the racing track. The goal is to use advanced control methods considering the vehicle kinematics to drive the vehicle with the best performance.

The thesis follows the previous work of Martin Vajnar [1] which focus on building of the racing platform and processing of the sensor data. The design of control system is then following the work of Jan Filip [2] which deals with the task of trajectory tracking formalized as a servomechanism problem and come up with solution tested on simulations.

1.1 Motivation

The motivation of this work is to create a solution for F1/10 autonomous driving competition, which will be used in upcoming race round. In previous rounds, most of the solutions were reactive algorithms, which did not consider the track layout or vehicle kinematics structure. Even though the presented solutions were functional and shown a good performance, it turned out, that reactive control approach is not able to handle all situations efficiently. Because of that, the map-based approach is introduced, which is able to localize the vehicle on the track and gives new options for vehicle control by high-level planning.

The second motivation of this work is, that developed localization of car models creates good testing conditions for the development of applications related to autonomous driving.

Such applications have to be tested on various scenarios to prove robustness and reliability. Testing those scenarios on car models instead of real cars is then much easier and cheaper.

1.2 Work Outline

In Chapter 2, the thesis describes the motivation and rules of F1/10 autonomous driving competition, introduce the racing platform, and review the solutions presented in previous rounds of the race. In Chapter 3 the scan-matching problem is outlined as a way how to perform Simultaneous Localization and mapping (SLAM) and the Hector SLAM method will be described. In Chapter 4, the Monte Carlo Localization (MCL) will be used to achieve a vehicle localization on a 2D map with the data from LiDAR. This Chapter also compares several methods of ray-casting and introduce two extensions, which use the data from wheel odometry to improve MCL position estimation. Chapter 5 analyze the process of simple automatic trajectory planning on the racing track for testing purposes and discuss the problem of trajectory utilization for time optimal racing. Finally, the last Chapter 6 focus on advanced control of the vehicle introduced as trajectory tracking.

Chapter 2

Background

Several competitions in the field of autonomous driving have been announced in the recent past to challenge different types of tasks. The *DARPA grand challenge* in 2004 [3] and *DARPA urban challenge* in 2007 [4] were one of the first large-scale competitions which aimed to develop a driver-less vehicle able to move in different terrains and handle basic traffic rules. The *Audi autonomous driving cup* challenge participants to build fully automatic driving functions and the necessary software architectures on 1/8 scaled car models. *Roborace* deals with the task of autonomous driving car able to race manually driven vehicles on a racing track. This thesis focus on solution of F1/10 autonomous driving competition, which challenge to race with scaled vehicles by 1/10.

This Chapter gives the reader background to the competition rules and motivation in Section 2.1 and provides the reader basic overview of the racing task. Then, in Section 2.2, describes the structure and equipment of the racing platform used in this thesis with preview of abilities of its components. Section 2.3 summarizes the reactive with map-based control strategy and highlights their main advantages and disadvantages regards to already utilized solutions in previous rounds of F1/10 competition. Section 2.4 follows with review of control methods possibly used to perform vehicle steering task along the racing track.

2.1 F1/10 competition

The F1/10 is a worldwide competition of scaled autonomous cars announced by the University of Pennsylvania which deals with the task of developing a software able to race with a down-scaled vehicle model on the racing track. Racing with the scaled platforms in contrast to real cars makes development affordable, easy to test and gives an opportunity to small student teams to bring their ideas

Since the key phrase of the competition is “The battle of algorithms”, the task does not rely on building a vehicle itself but limits the teams with hardware requirements to provide similar racing conditions. The idea of having a platform with same abilities pushes participant to focus on the control structures with different kinds of approaches. Organizers also rely on providing all the functional solutions open-source to the community, thus the abilities of vehicles are getting better every round of the race. The task of racing and handling vehicle in high speeds constantly discovers new bottlenecks of algorithms and force participant to come up with more complex solutions.

2.2 Vehicle platform description

The F1/10 racing platform is originally build on a Traxxas RC rally car and customized with several components. The competition organizers provides detailed instructions of building procedure [5], same as the [1], which also focuses on processing the data from sensors.

Figure 2.1: Racing platform

2.2.1 Sensors and perception

The racing car perceives the environment with several sensors. The most significant component is the LiDAR or optionally the stereo camera, which is able to measure distances from objects around the vehicle. Rules of the competition do not define the specific place where the LiDAR has to be mounted and even utilization of multiple LiDARs is allowed. However, for performing the task of localization and mapping the current configuration shown in 2.1 is sufficient.