Hochschule Aalen

Entwicklung von Navigationssoftware für mobile Robotersysteme und Simulation

by

Tristan Schwörer

Matriculation number: 71336

A bachelor thesis submitted in partial fulfillment of the requirements for the degree of the

Bachelor of Engineering (B. Eng.)
in Mechatronics
at Aalen University

Supervisor:
Prof. Dr. Stefan Hörmann (Aalen University)

Submitted on:
April 13$^{\text{th}}$, 2021

Preface

This bachelor thesis is part of the bachelor program in mechatronics at Aalen University and is supposed to take place in the 7$^{\text{th}}$ Semester. It covers the theoretical and practical work between November 2$^{\text{nd}}$ 2020 and April 9$^{\text{th}}$ 2021.

This work took place at the laboratory for mobile roboic systems of the faculty optics and mechatronics at aalen university and was completely independent of any other party and company.

Diese Bachelorarbeit ist fester Bestandteil des Bachelorprogramms Mechatronik an der Hochschule Aalen und soll im siebten Semester statt finden. Die hier dokumentierte Arbeit wurde zwischen dem 2. November 2020 und dem 13. April 2021 realisiert.

Die praktische sowie die theoretische Arbeit fand im Labor für mobile Robotersysteme der Fakultät Optik und Mechatronik an der Hochschule Aalen statt und ist komplett unabhängig von jeglicher anderen dritten Partei oder Firma.

Abstract

This bachelor thesis is about the concept, setup/development and testing of a software stack used for the autonomous navigation in an environment defined by the rules of the carolo cup.

The aim of this stack is lane following and obstacle avoidance based on a sensor data of the environment. This thesis extends the work of Prof. Hörmann who provided the road detection and is supposed to be used by the carolo cup team of university aalen in the future. Even though the robot used in this thesis does not satisfy the rules of the carolo cup the stack should be configurable for different robots aswell.

The robot is equipped with a lidar, a camera, wheel encoders and an imu. The data of these sensors will be filtered and processed using existent ros packages as well as newly developed ones. The resulting data will be fed into the navigation stack that then determines the best route for the robot.

Since there wasn't a driving robot available at the start of this thesis the task of simulating the robot with all of its sensor data and actors has been incorporated into the subject of this work.

Kurzfassung

Diese Bachelor-Thesis handelt von der Erstellung eines Konzepts, dem Aufbau und der Entwicklung eines “Software-Stack” und dessen Testens für die autonome navigation in einer, durch das Regelwerk des carolo cups beschriebenen, Umgebung.

Das Ziel dieses “Software-Stacks” ist, der Spur einer Straße zu folgen und dabei potentiellen Hindernissen auf der Straße auszuweichen. Diese Thesis führt die Arbeit von Prof. Hörmann der die von ihm Entwickelte Spurerkennung zur Verfügung stellte und soll in der Zukunft vom Carolo-Cip Team der Hochschule Aalen verwendet werden können. Obwohl der in dieser Arbeit verwendete Roboter nicht konform zum Regelwerk des Carolo-Cups ist, soll der Stack auch für andere Roboter konfigurierbar sein.

Der Roboter verfügt über einen Lidar, eine Kamera, Rad-Encoder und einen IMU (inertia measurement unit). Die Daten dieser Sensoren werden gefiltert und dann mit bestehenden ros packages und selbst entwickelten aufbereitet. Die resultierenden Daten werden dann an den Navigation Stack übergeben, der dann die beste Rute ermittelt.

Da zu Beginn dieser Arbeit kein vollständig funktionierender Roboter verfügbar war wurde das Teilthema der Simulation des Roboters mitsamt aller seiner Sensoren und Aktoren in das Thema der Thesis aufgenommen.

Acknowledgement

At this point I would like to thank the following people for supporting me during my bachelor thesis:

- **Prof. Dr. Stefan Hörmann** for being my supervisor during this time and for allways helping me with new ideas and approaches.
- **Prof. Dr. Arif Kazi** for being the second supervisor and helping me with ideas regarding the structure of the thesis.

Extending to that i would like to thank my Family and Friends that supported me during this period.

Table of Contents

1. Theoretical Background

This chapter will cover the needed theoretical background about the Gazebo Simulation, the Sensor Plugins, ROS and all of the used ROS packages.

1.1. ROS

1.1.1. Nodes

1.1.2. Plugins

1.1.3. Topics/Services/Actions

All three are possibilities for the data exchange between nodes.
According to ::::: Services and actions can be used like the subscriber/publisher structure but are meant for the intercommunication between nodes. A service is more or less a function in a different node that has the option to receive data and respond to it.

1.1.4. RVIZ

1.1.5. REP

REP's (short for ROS enhanced proposals) are guidelines made and maintained by the ros community. It is highly advisable to follow the guidelines as much as possible.
Complying to these guidelines allows external people easier comprehension of the structure of the robot and eliminates misunderstandings.
The most important REP's in this project are REP 103 and REP 105.

REP 103

"This REP provides a reference for the units and coordinate conventions used within ROS"[1]

Coordinate Frame

- **X-Axis** - Forward
- **Y-Axis** - Left
- **Z-Axis** - Up

Units

Units will always be represented in SI Units and their derived units.

The order of preference for rotations

1. Quaternion
2. Rotation matrix
3. fixed axis roll, pitch, yaw
4. Euler angles

[1]

REP 105

"This REP specifies naming conventions and semantic meaning for coordinate frames of mobile platforms used with ROS."[2]

REP103 Applies for all fixed coordinate frames.

Coordinate Frames

- **base_link** is a fixed frame on the robot base. It serves as the reference points for all of hardware mounted on the robot itself like sensors.
- **odom** is a world fixed frame that serves as the reference for the pose of the robot. Since the pose of the robot will drift over time it wont serve as a good long term reference.
  In most cases the odom frame will be computed using localization sensors like wheel odometry, imu's, visual odometry, etc. which leads to a continuous frame.
- **map** is a world fixed coordinate frame that serves as the reference for the odometry frame. It is also the base for a map of the environment such as the ones provided by slam algorithms. The frame is time discrete since it is mostly computed by localization algorithms.

That tree can be extended by an earth frame that would be the reference for the localization of the map in the earth. Which is useful, for long range robot platforms.[2]

1.1.6. TF

In most cases robots that are controlled by ros have a so called tf_tree. This tree is the coordinate frame structure of the robot. In it every sensor and actor has its own coordinate frame.

The structure in most trees of mobile platforms is quite similar which is caused by the REP105 (ROS Enhanced Proposals) this contains a definition of recommended names for the robot frames and their order in the tree. But it should be noted that not every frame that is defined in the norm has to be in every tree. The basic structure mostly starts at a so called fixed frame. This Frame will be the not changing frame in the environment. At moving robots this is often earth, map or odom, while in stationary robots this can even be base_link.

The tree is normally build up like in the following image.
TF2 is the successor of TF and is a very powerful tool in the ROS environment. With it it is possible to transform sensor_msgs and geometry_msgs from one frame in another. Furthermore it offers the possibility to transform old data into the present or at any other point in the past.

Robot Hardware Description

The robot hardware description consists of one or more URDF(Unified Robot Description Format) based xml file. Its purpose is to define the shape and geometric of every part of the robot.

robot_state_publisher

This package uses the robot hardware description and builds up the tf_tree using static_transform_publishers.

1.2. Gazebo

1.2.1. Plugins

Gazebo offers a wide selection of pre made plugins that can be incorporated into a simulated robot by attaching the plugin to the right tf_frame and configuring its parameters.

Camera

Lidar

Differential Controller

IMU

1.2.2. Models

1.3. navigation stack

1.3.1. mobe_base

1.3.2. global_planner

base_global_planner

1.3.3. local_planner

teb_local_planner

base_local_planner

dwa_local_planner

1.3.4. costmap_2d

global map

local map

layer

1.4. cartographer

1.5. Carolo-Cup

The carolo cup is an event hosted by the University Braunschweig and is an event in which the teams of many different universities can compete against each other and present their work and progress in the field of autonomous driving.
There are two different levels of difficulty the carolo basic cup and the carolo master cup.

2. Experimental

In this chapter the setup and qualification process of the the optical and mechanical system is explained.

2.1. Concept

2.2. Simulation

2.2.1. modeling

2.2.2. world

2.2.3. robot setup

URDF and xacro

plugin setup

2.3. SLAM

2.4. Navigation

2.4.1. Planner

2.4.2. markfreespace

2.4.3. dynamic_cost_layer

2.5. Odometry

2.5.1. Encoder

2.5.2. IMU

2.5.3. Improvement using SLAM

2.6. Laser_Filter

2.7. PoseFinder

2.7.1. Approximations

2.7.2. goalfrommap

3. Results and Discussion

4. Conclusion

4.1. Personal conclusion

5. Outlook

6. List of Figures

7. List of Tables

8. References

[1] Mike Purvis Tully Foote. *Standard Units of Measure and Coordinate Conventions.* `https://www.ros.org/reps/rep-0103.html`. Accessed: 2021-02-20. Oct. 7, 2010.

[2] Wim Meeussen. *Coordinate Frames for Mobile Platforms.* `https://www.ros.org/reps/rep-0105.html`. Accessed: 2021-02-20. Oct. 27, 2010.

Appendix

A. Additional Topics

B. Source Code

Eidesstattliche Erklärung

Name: Schwörer | **Vorname:** Tristan
Matrikel-Nr.: 71336 | **Studiengang:** Mechatronik

Hiermit versichere ich, **Tristan Schwörer**, an Eides statt, dass ich die vorliegende Bachelorarbeit
an der **Hochschule Aalen**
mit dem Titel **„Entwicklung von Navigationssoftware für mobile Robotersysteme und Simulation"**
selbständig und ohne fremde Hilfe verfasst und keine anderen als die angegebenen Hilfsmittel benutzt habe. Die Stellen der Arbeit, die dem Wortlaut oder dem Sinne nach anderen Werken entnommen wurden, sind in jedem Fall unter Angabe der Quelle kenntlich gemacht.

Ich habe die Bedeutung der eidesstattlichen Versicherung und prüfungsrechtlichen Folgen (§23 Abs. 3 des allg. Teils der Bachelor-SPO der Hochschule Aalen) sowie die strafrechtlichen Folgen (siehe unten) einer unrichtigen oder unvollständigen eidesstattlichen Versicherung zur Kenntnis genommen.

Auszug aus dem Strafgesetzbuch (StGB)

§156 StGB Falsche Versicherung an Eides Statt Wer von einer zur Abnahme einer Versicherung an Eides Statt zuständigen Behörde eine solche Versicherung falsch abgibt oder unter Berufung auf eine solche Versicherung falsch aussagt, wird mit Freiheitsstrafe bis zu drei Jahren oder mit Geldstrafe bestraft.

Ort, Datum

Unterschrift