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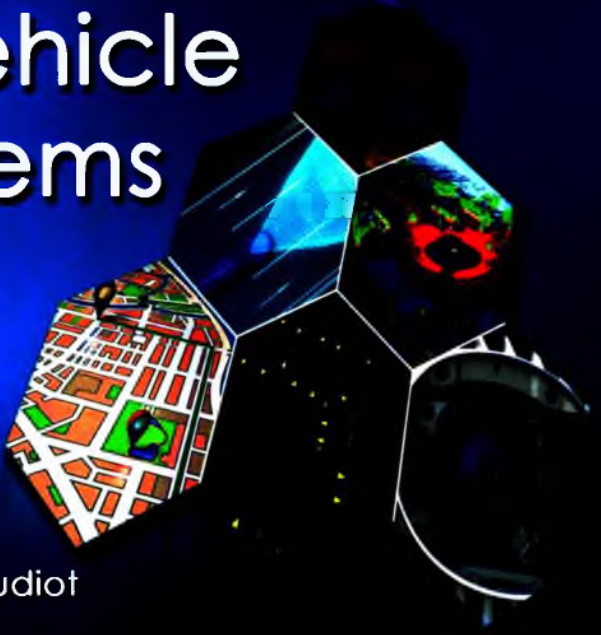
Creating Autonomous Vehicle Systems



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www.morganclaypool.com

ISBN: 9781681730073 print
ISBN: 9781681730080 ebook
ISBN: 9781681731674 epub

DOI: 10.2200/S00787ED1V01Y201707CSL009

A Publication in the Morgan & Claypool Publishers series
SYNTHESIS LECTURES ON COMPUTER SCIENCE, #9

Series ISSN: 1932-1228 Print 1932-1686 Electronic

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ABSTRACT

This book is the first technical overview of autonomous vehicles written for a general computing and engineering audience. The authors share their practical experiences of creating autonomous vehicle systems. These systems are complex, consisting of three major subsystems: (1) algorithms for localization, perception, and planning and control; (2) client systems, such as the robotics operating system and hardware platform; and (3) the cloud platform, which includes data storage, simulation, high-definition (HD) mapping, and deep learning model training. The algorithm subsystem extracts meaningful information from sensor raw data to understand its environment and make decisions about its actions. The client subsystem integrates these algorithms to meet real-time and reliability requirements. The cloud platform provides offline computing and storage capabilities for autonomous vehicles. Using the cloud platform, we are able to test new algorithms and update the HD map—plus, train better recognition, tracking, and decision models.

This book consists of nine chapters. Chapter 1 provides an overview of autonomous vehicle systems; Chapter 2 focuses on localization technologies; Chapter 3 discusses traditional techniques used for perception; Chapter 4 discusses deep learning based techniques for perception; Chapter 5 introduces the planning and control sub-system, especially prediction and routing technologies; Chapter 6 focuses on motion planning and feedback control of the planning and control subsystem; Chapter 7 introduces reinforcement learning-based planning and control; Chapter 8 delves into the details of client systems design; and Chapter 9 provides the details of cloud platforms for autonomous driving.

This book should be useful to students, researchers, and practitioners alike. Whether you are an undergraduate or a graduate student interested in autonomous driving, you will find herein a comprehensive overview of the whole autonomous vehicle technology stack. If you are an autonomous driving practitioner, the many practical techniques introduced in this book will be of interest to you. Researchers will also find plenty of references for an effective, deeper exploration of the various technologies.

KEYWORDS

autonomous driving, driverless cars, perception, vehicle localization, planning and control, autonomous driving hardware platform, autonomous driving cloud infrastructures

Contents

Preface

Autonomous vehicles, be they on land, on water, or in the air, are upon us and are finding a myriad of new applications, from driverless taxi services to automatic airborne surveillance of sensitive remote areas. Continued technological advances in the past few decades have made these innovations possible, but the design problems which must be surmounted in order to provide useful, efficient, and, supremely importantly, safe operations of these independent units are equally numerous and daunting.

It is thus the purpose of this book to provide an overview of these problems and lead the reader through some common design solutions. High technological capabilities, complete integration of hardware and software, and deep synergy with resident platforms (such as cloud servers) are a must for an eventual successful deployment. The focus is on land vehicles, and more specifically cars in urban or country road environments, as well as off-road operations. The aim of this book is to address an audience of engineers, be they from the academic or the industrial side, with a survey of the problems, solutions, and future research issues they will encounter in the development of autonomous vehicles, from sensing, perception to action, and including support from cloud-based servers. A copious amount of bibliographic references completes the picture and will help the reader navigate through a jungle of past work.

STRUCTURE OF THE BOOK

A brief history of information technology and an overview of the algorithms behind autonomous driving systems, of the architecture of the systems, and of the support infrastructure needed is provided in Chapter 1. Localization, being one of the most important tasks in autonomous driving, is covered in Chapter 2 where the most common approaches are introduced. The principles, advantages, and drawbacks of GNSS, INS, LiDAR, and wheel odometry are described in detail and the integration of various versions of these strategies are discussed. As for detection, i.e., "understanding" the environment based on sensory data, it is described in Chapter 3, with an exploration of the various algorithms in use, including scene understanding, image flow, tracking, etc. The large datasets, highly complex computations required by image classification, object detection, semantic segmentation, etc. are best handled by the deep learning approaches to perception advocated for in Chapter 4, where applications to detection, semantic segmentation, and image flow are described in detail. Once the environment is understood by the autonomous vehicle, it must somehow predict future events (e.g., the motion of another vehicle in its vicinity) and plan its own route. This is the purpose of Chapter 5. Next (Chapter 6), comes an even more detailed level of decision making,

planning, and control. Feedback between modules with possibly orthogonal decisions as well as conflict resolution (e.g., one module could recommend a lane change, but another one has detected an obstacle in the lane in question) are covered with an emphasis on describing algorithms for behavioral decision making (e.g., Markov decision processes, scenario-based divide and conquer), and for motion planning. This is what leads us into Chapter 7 for a demonstration of the need to supplement the design with Reinforcement Learning-based Planning and Control for a complete integration of situational scenarios in the development of an autonomous system. Underneath it all, the on-board computing platform is the topic of Chapter 8. It includes an introductory description of the Robot Operating System, followed by an actual summary of the real hardware employed. The need for heterogeneous computing is introduced with a strong emphasis on meeting real-time computing requirements as well as on-board considerations (power consumption and heat dissipation). This means that a variety of processing units (general-purpose CPU, GPUs, FPGAs, etc.) must be used. Finally, Chapter 9 covers the infrastructure for the cloud platform used to "tie it all together" (i.e., provide services for distributed simulation tests for new algorithm deployment, offline deep learning model training, and High-Definition (HD) map generation).