Advances in Industrial Control

Péter Gáspár
Balázs Németh

Predictive Cruise Control for Road Vehicles Using Road and Traffic Information

Springer

Advances in Industrial Control

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Indexed by SCOPUS and Engineering Index.

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ISSN 1430-9491 ISSN 2193-1577 (electronic)
Advances in Industrial Control
ISBN 978-3-030-04115-1 ISBN 978-3-030-04116-8 (eBook)
https://doi.org/10.1007/978-3-030-04116-8

Library of Congress Control Number: 2018960760

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Series Editor's Foreword

Control systems engineering is viewed very differently by researchers and those that practice the craft. The former group develops general algorithms with a strong underlying mathematical basis while for the latter, concerns over the limits of equipment and plant downtime dominate. The series *Advances in Industrial Control* attempts to bridge this divide and hopes to encourage the adoption of more advanced control techniques when warranted.

The rapid development of new control theory and technology has an impact on all areas of control engineering and applications. There are new control theories, actuators, sensor systems, computing methods, design philosophies, and of course new application areas. This provides justification for a specialized monograph series, and the development of relevant control theory also needs to be stimulated and driven by the needs and challenges of applications. A focus on applications is also essential if the different aspects of the control design problem are to be explored with the same dedication the synthesis problems have received. The series provides an opportunity for researchers to present an extended exposition of new work on industrial control, raising awareness of the substantial benefits that can accrue, and the challenges that can arise.

The authors are well known for their work on vehicle control systems, driver assistance systems, and traffic flow. This book is concerned with the design of an automated longitudinal control system for vehicles to enhance the capabilities of adaptive cruise control systems. There are two optimization problems where a balance in performance is required involving the longitudinal control force to be minimized and the traveling time that must also be minimized. There is clearly a conflict in the wish to minimize energy whilst reducing journey times so a natural optimization problem arises. It is assumed that the vehicle has information about the environment and surrounding vehicles which is much easier to achieve with recent developments in sensor technology for autonomous vehicles. The predictive cruise control aims to balance the need for energy saving against journey time according to the needs of the driver. The major sections of the text cover *Predictive Cruise Control*, the *Analysis of the Traffic Flow*, and *Control Strategies*.

There is a huge interest in all aspects of vehicle control systems and traffic flow control. This book covers many of the important topics such as traffic and platoon control, and it describes the main areas of control methodologies, modeling, design, simulation, and results. The main focus of the book is to ensure that the velocity of the vehicle is controlled so that the global and local information about traveling and the environment is taken into consideration. Such work is clearly important for both safety and the environment, and it is therefore a welcome addition to the series on *Advances in Industrial Control*.

Glasgow, UK
October 2018

Michael J. Grimble

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Chapter 1
Introduction

Introductory Thoughts

The automation of road transport systems has recently become the main focus of researchers and automotive companies as well. Several car manufacturers have already introduced autonomous vehicle functions which can be regarded as milestones in the development of fully autonomous or self-driving vehicles. Research on next generation of adaptive cruise control and cooperative adaptive cruise control systems generally focuses on enhancing the performances of the system by considering driver behavior.

In particular, the development of an energy-efficient operation strategy for road vehicles has been in the focus. The purpose of the strategy is to design the speed of road vehicles taking into consideration several factors such as control energy requirement, fuel consumption, road slopes, speed limits, emissions, and traveling time. These optimization criteria lead to multi-objective solutions.

Certainly, other approaches are also used. In crossing an intersection, the most important consideration is to ensure the continuity of the traffic, i.e., the continuity of the passage of cars. If a car needs to slow down or stop at an intersection due to other traffic, the capacity of the road decreases, the average speed of vehicles decreases, and fuel consumption increases. If the continuity of traffic can be guaranteed by using appropriately tuned traffic lights or other solutions, the abovementioned factors for the speed optimization are applied again.

The book focuses on the design of a multi-criteria automated vehicle longitudinal control system as an enhancement of the adaptive cruise control system. As in most of the longitudinal automated vehicle control systems, it is assumed that the vehicle has information about the environment and surrounding vehicles using wireless or Cloud-Based Vehicle-to-Infrastructure and Vehicle-to-Vehicle (V2I and V2V) communication technologies. In the speed design both the road and the traffic information is also taken into consideration. This leads to the predictive cruise

P. Gáspár and B. Németh, *Predictive Cruise Control for Road Vehicles Using Road and Traffic Information*, Advances in Industrial Control,
https://doi.org/10.1007/978-3-030-04116-8_1

control, which is able to create a balance between longitudinal energy saving and journey time according to preferences of the driver.

However, other drivers on the road have different priorities, which can lead to conflict, e.g., fast vehicles are held up by vehicles traveling in a fuel efficient fashion. The difficulty in the predictive speed design is to adapt to the motion of the surrounding vehicles. Making a decision to change lanes is a critical one, in which the conflicts between vehicles and tailbacks must be eliminated. Handling the preceding vehicle and considering the motion of the follower vehicle must be incorporated into the decision method. The combination of the concept of the predictive speed and the congestion problem leads to a more complex multi-criteria optimization task.

There is a strong interaction between the traffic flow and the individual vehicles. This interaction is analyzed from both a microscopic and a macroscopic point of view. According to the microscopic view, the vehicle equipped with predictive control has impact on the traffic flow, which differs from the human-driven vehicles. The parameter variations of the predictive control are analyzed through a sensitivity analysis.

In the macroscopic view, the individual vehicle is incorporated into the global traffic flow. The control of the macroscopic traffic flow and that of the individual microscopic vehicles are handled simultaneously. The purpose is to analyze the effects of different parameters on the average traffic speed and the traction force of the vehicles in the mixed traffic flow by using a macroscopic point of view. The control of the individual vehicles and the traffic control are handled simultaneously, consequently, a trade-off between the parameters of the microscopic and the macroscopic models has been achieved. The purposes of the control design are to avoid congestion through the stability of the system, minimize energy consumption, and reduce the queue length at the control gates.

Another important analysis is related to the platoon control, in which a group of vehicles are traveling at the same speed together. This speed is realized by the leader vehicle, which is followed by the other vehicles. Consequently, the common speed usually deviates from the optimal speed of the individual vehicles. The main task in the design phase is to determine the common speed at which the velocities of the members are as close as possible to their own optimal velocity. Here, the stability analysis of the platoon control in which the predictive control design is used in the individual vehicles is a critical task.

The speed control proposed in the book is analyzed and verified both in a simulation environment and in real circumstances. These solutions and their results will also be presented in the book.

1.1 Motivation Background Concerning Autonomous Vehicle Control

The main motivation of the research and development was the autonomous (or self-driving) cars. Nowadays, the automotive industry is changing continuously, affecting nearly almost every area of development. Concerning the powertrain system, alternative solutions such as hybrid and electric drives are spreading slowly but steadily. This process was further accelerated by the "diesel scandal", which exploded in 2015 and by the verdict of the German federal court in February 2018, which allowed the ban of diesel vehicles with an environmental category lower than Euro 6.

A fast developing area is the Advanced Driver Assistance Systems (ADAS). The original purposes of ADAS systems were to design and implement components and functions to support the driver in the driving process and enhance safety, see, e.g., Gáspár et al. (2017), Sename et al. (2013). The goals of the researchers and developers today are to increase the levels of automated solutions and prepare functions and components to achieve fully automated vehicles to travel on roads. These developments have had a great impact on two technology areas. One is modern wireless info-communication solutions, and the other is artificial intelligence, including machine learning. Since traditional car makers and suppliers have had no prior knowledge of these areas, large IT companies are presented with great possibilities in the vehicle industry. In recent years, this has had a profound effect on developments, among which there are positive and negative examples.

One of the most significant developments is Google's self-driving cars, which are tested in certain cities in Arizona as part of a public pilot project called Waymo, see Waymo (2017). Developers are very serious about safety and both virtual and real-world tests.

Unfortunately, negative experiences have also been found in recent years. One, which is related to the Tesla Autopilot system, has led to a fatal accident. In another sad incident, Uber's self-test vehicle under human supervision run over a bicycle. Because of the hot topic of the autonomous vehicles, developers try to produce results as quickly as possible and do not always follow the security and testing procedures that have been proven by traditional vendors. All of these raise serious ethical issues that could jeopardize the social acceptance of self-driving vehicles.

An autonomous car (also known as a self-driving car) is a vehicle that is capable of sensing its environment, evaluating the real situation, making decision without human interventions, and moreover, activating the components of actuators. Regarding autonomous vehicles, three main tasks to be solved must be highlighted. The first is sensing the environmental, in which a space around the vehicle is monitored continuously applying several sensors and sensor fusion methods. Its purpose is to achieve the most accurate and reliable model of the environment. The second is the situation assessment, in which the system evaluates the given traffic situation based on the environmental situation in order to prepare an adequate decision. This is usually complemented by making the appropriate decision on the maneuvre required in the given situation. The third task is to design a vehicle control and implement it in a safe and reliable way.

In order to determine to what extent the components and functions of different manufacturers and suppliers are suitable for self-drive vehicles, Society of Automotive Engineers (SAE) has introduced a six-level system of requirements in Recommendation J3016. Although the currently implemented autonomous components are at level 2, manufacturers and suppliers are promising levels 4 and 5 within 5–10 years. Moreover, it is important to note that the current transport environment is designed for human perception. The human abilities and experience that a driver uses are extremely difficult to create by using different software systems. There are many unclear or even contradictory traffic situations on the roads. These tasks are often solved by the drivers in an intuitive way and/or by having interaction with the other participants in the traffic. Special situations are very difficult to handle in an automated manner, therefore much clearer traffic rules and better controlled infrastructure are required.

In the current trends, the topics of electromobility and autonomous vehicles have priority. In the former, a partially solved and relatively well-defined problem, i.e., energy storage, should be managed. In the latter topic, there are a large number of unsolved problems concerning regulatory and ethical issues. Nevertheless, in both areas, manufacturers have ambitious plans for a similar span of time, claiming that within a year, level 3 functions and systems will appear, and between 2020 and 2025, levels 4 and 5. However, level 3 systems are still not available in mass production. Accordingly, prediction and promises concerning level 4 and especially the level 5 are welcome with serious reservations. As an example in the Waymo project, a set of cars can be used by volunteer drivers. These vehicles only travel within the cities but completely autonomously without human intervention. This is foreseeing that within a few years, even though a limited area, autonomous vehicles, which can be used by anyone, will appear.

As far as the research and development directions are concerned, the picture is much clearer. In the field of sensors, it is typical that all manufacturers want to cover their vehicles in full space (360°) in a redundant manner, multirange and viewing angles. Manufacturers require technologies in which camera, radar, ultrasound, and lidar sensors are applied simultaneously. Some developers are trying to handle tasks using a pure camera-based solution but they must prove the acceptable reliability. The first three technologies have already become widespread in vehicles owing to their low cost. Although the price of lidar sensors is steadily decreasing, it is still too expensive for mass production. The sensor sets differ with each manufacturer, but there is a broad consensus in the principles. Another important trend where developers' views are also relatively consensual is the application of artificial intelligence, e.g., machine learning methods, in the new complex tasks. Almost everyone agrees that the current rule-based algorithms alone cannot solve all complex perception, situational assessment, and control tasks.

In the forefront of research and development are autonomous functions. The challenge is that the control systems of vehicles must be synchronized with the environment. In the task focused on in the book, the velocity of the vehicle must be designed and implemented in such a way that global and local information about traveling and the environment is taken into consideration. Global information may include the required driving/delivery time, fuel consumption, road slopes, road conditions, speed limits, road stability, and safety. Local information is the speeds of the vehicles on the road, congestions, but also road constructions affecting speed. As a vehicle with speed control is a participant in traffic, it is likely to affect the traveling of vehicles in its environment, but these vehicles also influence the speed design. It is important that the vehicle with speed control must not interfere with or threaten the continuous and safe travel other vehicles involved in the traffic. The vehicle has different impacts during traveling that must be taken into account when driving, e.g., the slower speed of the vehicle ahead of it, the higher speed of the vehicle behind it, and the congestion of the traffic.

The introduction of new technologies poses challenges to be met. The successful algorithms must be tested and validated, which will be a huge task for developers and approval authorities. During the testing, situation-based cases must be examined instead of functional cases. According to the industry's estimation, it requires several million of kilometers of testing, which is time consuming and expensive. Moreover, this requirement encourages the simultaneous application of simulation-based solutions. Another new problem to be solved is the safety of the Wireless Technology (Connected Car) used by autonomous cars. These systems are currently found in the entertainment and comfort features of vehicles, which can be used to connect personal "smart devices" to the vehicle. An important area of applications is Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) networks. Using these networks, vehicles are able to exchange their driving dynamics and remotely access the infrastructure signals and status. In this way, vehicles are able to increase the reliability of sensor data and even give new tools to the authorities in traffic control or enforcement. At the same time, it must be accepted as a fact that wireless communication is physically "open". Consequently, the protection of property and personal data will be a new safety task. Moreover, it is necessary to prepare for attacks that can cause traffic anomalies or even accidents.

1.2 Structure of the Book

The book is organized as follows. Chapter 1 presents the motivation background of the research and development of the speed control.

The book is organized around three main parts. The first part focuses on the basis of the predictive cruise control, see Part I.

Chapter 2 presents the basics of the predictive cruise control. The purposes of the speed design are to reduce longitudinal energy requirement and fuel consumption while traveling time remains as short as possible. In the calculation, the road slopes, the speed limits, and the average speeds of the road sections are taken into consideration. By choosing the appropriate velocity according to the road and traffic information, the number of unnecessary accelerations and brakings, moreover, their durations can be significantly reduced. The cruise control design leads to two optimization problems: the longitudinal control force must be minimized; the traveling time must be minimized. In the design, a balance between the two performances must be achieved.

In the design of predictive cruise control, road and traffic information must be taken into consideration. This is the subject of Chap. 3. However, other drivers on the road have different priorities, which can lead to conflict. For example, since the vehicle may catch up with a preceding vehicle, it is necessary to consider its speed. In another example, since the vehicle preferring energy saving is traveling in traffic, it may be in conflict with other vehicles preferring cruising at the speed limit. The goal of the research is to design an optimal predictive control strategy which is able to adapt to the motion of the surrounding vehicles. The combination of the predictive cruise control concept and the congestion problem leads to a complex multi-criteria optimization task. Moreover, a decision algorithm of the lane change is developed. During the lane change, safe operation must be guaranteed and the conflicts between vehicles and tailbacks must be prevented. Handling the preceding vehicle and considering the motion of the follower vehicle must be incorporated into the decision method.

Chapter 4 focuses on the conflict situations in intersections, in which both the safety and the energy-efficient motion of the traffic must be simultaneously guaranteed. However, if a fault occurs in an infrastructure element, these criteria cannot be guaranteed by the traffic control system. The method uses an energy-optimal look-ahead algorithm which considers the motion of the other vehicles, topographic, and road information. The operation of the vehicle control results in an energy-efficient cruising of the controlled vehicle, adapting to the priorities of the other vehicles in the intersection.

The second part focuses on the analysis of the traffic flow both in microscopic and macroscopic point of view, see Part II.

Chapter 5 analyzes the relationship between the traffic flow and the cruise control from the microscopic point of view. There is a relationship between the traffic flow and the predictive cruise control, i.e., they interact strongly with each other. Since the speeds of the individual vehicles affect the speed of the traffic flow, a sensitivity analysis of the parameter variation in the predictive control is performed. If traffic information is also considered in the predictive control, an undesirable side effect on the traffic flow may occur. Therefore, in the cruise control design, both the individual energy optimization and its impact on the traffic flow are elaborated. A method is developed by which the unfavorable effect of the traffic flow consideration can be reduced. In the simulation examples, the speed design is performed in Matlab/Simulink while the analysis is carried out in CarSim and TruckSim simulation and visualization environments.

Chapter 6 analyzes the impact of cruise control on the traffic flow from the macroscopic point of view. The model of the macroscopic traffic flow, the control of traffic dynamics, and the optimization of the individual microscopic vehicles are coordinated. Thus, the individual vehicle is incorporated into the global traffic flow. Since the speed profile of the vehicle equipped with predictive speed control may differ from that of the conventional vehicle, the characteristics of the traffic flow change. The purpose is to analyze the effects of different parameters on the average traffic speed and the traction force of the vehicles in the mixed traffic flow by using a macroscopic point of view. Three components of the traffic system are chosen, such as the inflow of the vehicles on the highway section, the ratio of the vehicles equipped with speed control in the entire traffic, and the energy-efficient parameter of the design of the predictive cruise control. In the analysis, the VisSim simulation environment is applied.

The third main part develops several control strategies for the ramp metering control of the traffic dynamics and presents briefly the implementation of the speed control, see Part III.

The macroscopic modeling and dynamic analysis of the mixed traffic flow, the ramp metering control of the traffic dynamics, and the optimization of the predictive cruise control of the microscopic individual vehicles are coordinated in Chap. 7. The control of the individual vehicles and the traffic control are handled simultaneously, consequently, a trade-off between the parameters of the microscopic and the macroscopic models has been achieved. The purposes of the stability control are to avoid congestion, minimize energy consumption, and reduce the queue length at the control gates. The so-called maximum controlled invariant set provides a stability analysis of the traffic system and calculates the maximum vehicle number which can enter the traffic network. This control system guarantees both the stability of the entire traffic and energy and time optimal intervention of automated vehicles.

In Chap. 8, a design method is developed in which the control of the macroscopic traffic flow and the cruise control of the local vehicles are coordinated. The contribution will be an optimization strategy, which incorporates the nonlinearities and the parameter dependency of the traffic system and the multi-optimization of the look-ahead vehicles. Consequently, a trade-off between the parameters of the microscopic and the macroscopic models has been created. In the method, the impact of traffic and vehicle parameters on the fundamental diagram is analyzed. In the control design, the MPC method is applied, with which the prediction of the traffic flow and that of the traveling of the vehicles are taken into consideration.

Chapter 9 focuses on data-driven coordination design of traffic control. The motivation is that the control of the traffic flow based on the classical state space representation for mixed traffic can be difficult due to the uncertainties, which leads to a data-driven approach. A data-driven coordinated traffic and vehicle control strategy is proposed, with which the inflow at the entrance gates and the speed profile of the eco-cruise controlled vehicles are influenced. Thus, the intervention possibilities are the green time of the traffic lights on the entrances and the speed profile of the cruise controlled vehicles. The advantage of the method is that in the proposed strategy, the fundamental diagram of the traffic dynamics, which contains several parameter uncertainties, is avoided.

In Chap. 10, the method is extended to vehicles in a platoon. The main idea behind the design is that each vehicle in the platoon is able to calculate its speed independently of the other vehicles. Since traveling in a platoon requires the same reference speed, the optimal speed must be modified according to the other vehicles.

In the platoon, the speed of the leader vehicle determines the speed of all the vehicles. The goal is to determine the common speed at which the cruising of the members is as close as possible to their respective optimal speed. The stability analysis of the platoon control in which the predictive cruise control is designed by using the speed control of the individual vehicles must be performed.

Chapter 11 focuses on the simulation and validation of the predictive cruise control. In order to analyze the operation of the predictive cruise control, a Hardware-in-the-Loop vehicle simulator has been built. Here, the CarSim and TruckSim simulation and visualization environments play central roles. The vehicle simulator has several purposes. It demonstrates the operation of the predictive cruise control and provides the possibility to select the different design and operation parameters. The predictive speed control can be compared to conventional cruise control solutions in the online environment. In the second part of the chapter, some results from the real validation are also presented. The chapter also includes the architecture of realized control and the test results.

In the Appendix, further components of the traffic control are included, see Part IV. Chapter "Model-based robust control design" briefly summarizes the main steps of the robust control design from the modeling to the synthesis. Chapter "Maximum controlled invariants sets" presents both the theoretical background and the practical computation method of the control invariant sets.

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Part I
Predictive Cruise Control

Chapter 2
Design of Predictive Cruise Control Using Road Information

Introduction and Motivation

As a result of growing global requirements, the automotive researchers are forced to develop flexible, reliable, and economical automotive systems which require less energy during the operation. Reducing fuel consumption is an important environmental and economic requirement for vehicle systems. Since the driveline system has an important role in the emission of the vehicle, the development of the longitudinal control systems is in the focus of the research and development of the vehicle industry. This chapter presents a method of how the required force and energy, and thus fuel consumption can be reduced when the external road information is taken into consideration during the journey. Moreover, it proposes the design of a new adaptive cruise control system, in which the longitudinal control incorporates the brake and traction forces in order to achieve the designed velocity profile.

The controllers applied in current adaptive cruise control systems are able to take into consideration only instantaneous effects of road conditions since they do not have information about the oncoming road sections. The cruise control systems automatically maintain a steady speed of a vehicle as set by the driver by setting the longitudinal control forces. In the following, road inclinations are taken into consideration in the design of the longitudinal control force. The aim in this calculation is to achieve a control force which is similar to the driver's requirement. For example, in front of the downhill slope, the driver can see the change in the curve of the road. Here the velocity of the vehicle increases, thus the control force of the vehicle before the slope can be reduced. As a result, at the beginning of the slope, the velocity of the vehicle decreases, thus it will increase from a lower value. Consequently, the brake system can be activated later or it may not be necessary to activate it at all. If the velocity in the next road section changes, it is possible to set the adequate control force. In the knowledge of the speed limits, it is also possible to save energy. Moreover, in the section of the road where a speed limit is imposed different strategies can be considered. Before the regulated section, the velocity can be reduced, therefore

P. Gáspár and B. Németh, *Predictive Cruise Control for Road Vehicles Using Road and Traffic Information*, Advances in Industrial Control,
https://doi.org/10.1007/978-3-030-04116-8_2

less energy is necessary for the vehicle. Using the idea of road slope and speed limit, fuel consumption and the energy required by the actuators can be reduced. By choosing the appropriate velocity according to the road and traffic information, the number of unnecessary accelerations and brakings and their durations can be significantly reduced.

In the vehicle, the most important longitudinal actuators are the engine, the transmission and the brake system. The engine is set at a particular revolution with corresponding consumption, torques, etc. If road conditions are known, the engine can be operated more efficiently throughout the entire journey. The transmission system has effects on the engine since it creates a connection between the engine and the wheels. The selected gear affects the operation of the engine. Hence, the engine and the transmission system must be handled together in a control system. Moreover, the unnecessarily frequent activation of the brake is undesirable because of the wear of the brake pad/disc and the loss in kinetic energy. The control of longitudinal dynamics requires the integration of these vehicle components, see e.g., Kiencke and Nielsen (2000), Trachtler (2004).

The method takes into consideration both the inclination of the road and the speed limits. Vehicles save energy at the change of road inclinations and at the same time keep compulsory speed limits. In addition, the tracking of the preceding vehicle is necessary to avoid a collision. If the preceding vehicle accelerates or decelerates, the tracking vehicle must strictly track the velocity within the speed limit. Thus, this method changes the speed according to the road and traffic conditions. At the same time, the efficiency of the transportation system as an important cost factor requires relatively steady speed. These requirements are in conflict and the trade-off among them can be achieved using different weights.

Several methods in which the road conditions are taken into consideration have already been proposed, see Ivarsson et al. (2009), Nouveliere et al. (2008), Németh and Gáspár (2010). The look-ahead control methods assume that information about the future disturbances to the controlled system is available. To find a compromise solution between fuel consumption and trip time leads to an optimization problem. The optimization was handled using a receding horizon control approach in Hellström et al. (2010), Passenberg et al. (2009). In another approach, the terrain and traffic flow were modeled stochastically using a Markov chain model in Kolmanovsky and Filev (2009, 2010). In Hellström et al. (2009), the approach was evaluated in real experiments where the road slope was estimated by the method in Sahlholm and Johansson (2009). The work Faris et al. (2011) classifies several modeling approaches for vehicle fuel consumption and emission, such as microscopic, mesoscopic, and macroscopic modeling methods. From the aspect of microscopic approach, models of vehicle dynamics are preferred in the paper. Alternative truck lane management strategies are evaluated in Rakha et al. (2006). The efficiency of this method is presented by different scenarios, which show that using these methods travel time, energy, and the emission of the vehicle can be reduced. Rakha et al. (2006, 1989) present modeling methods for the design of route guidance strategies and the reliable estimation of travel time. The preliminary results of the research are also published in Németh and Gáspár (2010).

The aim of the design method is to calculate the longitudinal forces by using an optimization method. The optimal solution is built into a closed-loop interconnection structure in which a robust controller is designed using a Linear Parameter Varying (LPV) method. In the LPV method uncertainties, disturbances and nonlinear properties of the system are also handled. The real physical inputs of the system (throttle, gear position, and brake pressure) are calculated using the longitudinal force required by velocity tracking. By choosing the appropriate velocity according to the road and traffic information, the number of unnecessary accelerations and brakings and their durations can be significantly reduced. The specific components such as actuators occur in the implementation task. An important feature of the method is that the optimization task and the implementation task are handled separately. Consequently, the method can be implemented in an ECU (electronic control unit) in practice.

2.1 Speed Design Based on Road Slopes and Weighting Factors

In this section, the road inclinations and speed limits are formalized in a control-oriented model. First, the road ahead of the vehicle is divided into several sections and reference velocities are selected for them. The rates of the inclinations of the road and those of the speed limits are assumed to be known at the endpoints of each section. Second, the road sections are qualified by different weights, which have an important role in control design. The appropriate selection of the weights creates a balance between the velocity of the vehicle and the effects of road conditions. The knowledge of the road inclinations is a necessary assumption for the calculation of the velocity signal. In practice, the slope of the road can be obtained in two ways: either a contour map which contains the level lines is used, or an estimation method is applied. In the former case, a map used in other navigation tasks can be extended with slope information. Several methods have been proposed for slope estimation. They use cameras, laser/inertial profilometers, differential GPS or a GPS/INS systems, see Bae et al. (2001), Labayrade et al. (2002), Hahn et al. (2004). An estimation method based on a vehicle model and Kalman filters was proposed by Lingman and Schmidtbauer (2002). The detection of a speed limit sign is usually based on a video camera.

The principle of the consideration of road conditions is the following. It is assumed that the vehicle travels in a segment from the initial point (beginning of the road section) to the first division point. The velocity at the initial point is predefined and it is called original velocity. The journey is carried out with constant longitudinal force. The dynamics of the vehicle is described between the initial and the first division points. An important question is how velocity should be selected at the initial point (called modified velocity) at which the reference velocity of the first point can be reached using a constant longitudinal force. The thought can be extended to the next