Development of lateral control strategies after exiting the highway

/ Department of
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Systems Design

Development of Lateral Control Strategies After Exiting the Highway

Extending the Lateral Control in Non-Highway Scenarios

Executive Summary

October 2019

Gürbey Çeken

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Eindhoven University of Technology
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Public Executive Summary

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The design that is described in this report has been carried out in accordance with the rules of the TU/e Code of Scientific Conduct.

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Abstract	This report presents the development procedure of automated lateral control strategies for non-highway conditions. The objective is to assist the front camera applications by enriching and extending the driving horizon by utilization of the digital map technology and the target following strategies. The implementation focuses on specific driving conditions where the lane marker information is temporarily unavailable for the front camera. The validation is performed on a simulated environment using the real life test data per pre-defined use case scenarios. The V-model system engineering approach is followed during the course of the work.

Keywords	ADAS, Lateral Vehicle Control, Digital Maps, Environment Perception, Target Following, Lane Keep Assist

Foreword

As one of market leaders in the field of driver assistance systems, Valeo offers a camera-based system for lane centering and adaptive cruise control. The aim of this final project was to extend the availability of the current lane centering system. Increasing the availability is realized by using offline street and lane information to handle situations where a camera only system would have limited performance.

The project was divided into several milestones. Starting with understanding the existing system, problem definition and defining the project goal. Moving to System Engineering activities that includes formulating requirements, constructing system design and implementation and ending with testing and validation.

During the past months Guerbey showed good command of handling and managing the project. He was able to plan and adapt his milestones. His system engineering skills and knowledge helped a lot in setting the project goal as well as defining use cases. Guerbey was able to understand, analyze and propose technical solutions to problems he faced throughout the project. He demonstrated his ability to communicate and the capability to work as a part of an international environment. In general, we really appreciate Guerbey's hard work and dedication towards the project.

Thank you Guerbey for your contribution to our company and development.

Preface

This technical report presents the results of my final project for completing the Professional Doctorate in Engineering (PDEng) program in Automotive Systems Design (ASD) at the Eindhoven University of Technology (TU/e). The program focuses on strengthening the technical and non-technical skills related to effective and efficient design and development in a multi-disciplinary project environment. The research domain of the program consists of high-tech automotive systems such as automated and cooperative driving, smart mobility and fuel-efficient systems. The first fourteen months of the program, the trainees perform several projects for various companies from the automotive industry, while also additional courses and workshops are provided. The final part of the education includes a ten-month individual, challenging and innovative technological design project for an industrial partner.

In accordance with the program objectives and structure, this project was initiated on January 2019 in collaboration with the company Valeo Schalter und Sensoren GmbH, who is amongst the market leaders in comfort and driver assist systems. The topic of the research was based upon improving the existing camera-based lateral assist functionalities by utilization of additional environmental inputs, namely digital map data and preceding vehicle information. Valeo's existing lane centering systems were chosen as the baseline of the study. The ADASRP software provided the digital map platform as an input to the developed functionality. The output product aimed to extend the current functionality in specific non-highway conditions where the lane markers are not visible to the camera unit. The system was developed until the proof of concept level and the validation was performed on a simulated environment using recorded real-life driving data.

The target audience of this report is assumed to have some basic knowledge in areas like environmental perception, vehicle sensors, automotive technology, data fitting, optimization and system engineering.

Gurbey Ceken

October 2019

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Here, I would like to acknowledge everybody who supported me during the course of the project. I would not be able to achieve without the help of these highly intelligent and supportive people.

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My sincerest gratitude goes to the brilliant staff of Eindhoven University of Technology, for their great support and guidance. Firstly, I would like to thank to Prof. Dr. Henk Nijmeijer and Dr. Tom van der Sande for their intensive academic input to my work. I am especially grateful to Dr. Tom van der Sande for his endless efforts on keeping the project right on the track and sharing his deep know how whenever I needed. Moreover, I would like to extend my heartfelt gratitude to Ellen van Hoof-Rompen and Dr. Peter Heuberger for their overwhelming support throughout the PDEng program.

Furthermore, I would like to thank all the colleagues at Valeo for generously sharing their time and knowledge, namely, Jonathan Rogg, Graziano Nardelli, Mahmoud Aly, Fabian Fuchs, Urs Borrmann, Riadh Kalthoumi and Vladimir Gromov. It was great to work in a team of these smart engineers.

I would like to thank all my dearest colleagues from ASD and MSD for their support and friendship, filling the these two years with wonderful memories. My special thanks go to ASD alumni Bilgehan Bayar and Sharad Bhadgaonkar for helping me with their experience on the subject of my work, and also to Abhishek Sharma for supporting each other on the project related and other practical issues.

Last but not least, I would like to thank my parents Ayse and Ismet Ceken, my sister Gozde Ceken, my girlfriend Merve Yurtcan and my close friends. I would not have succeeded in my personal and professional life without their constant support.

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October 2019

1. Executive Summary

This chapter gives an overall overview of the project by providing preliminary concepts of the lane centering systems and the definition of the project context. Afterwards, research question and the project objectives are accordingly identified.

1.1. Background on Lateral Assist Systems

In recent years, one of the largest engineering efforts in automotive field has been given on development of the ADAS, in order to improve the safety and efficiency of road vehicles. The research and market in ADAS is expected to grow significantly in the upcoming years [1], by extending the current technology to a level that highly automated driving functions will be enhanced and feasible enough to be accessible in regular passenger cars.

One of the critical aspects of driving a road vehicle is maintaining its safe lateral position with respect to lane boundaries. This task can be challenging for a human driver since it requires a constant focus and imminent lane departure can occur in less than a second if the driving action is interrupted. A major cause of the accidents are caused by unintentional lane change, emphasizing the significance of the lane keeping action in terms of safety [2]. Sharing this heavy burden can relieve the stress on the driver and increase comfort. Hence, having a direct relation to safety and comfort, lane keeping action has been one of the main focus for ADAS applications.

There are readily commercialized solutions in the market that aid the driver with the lateral control of the vehicle. These applications have various types, each focusing on a different aspect of driving. For instance, a lane keep assist system (LKAS) constantly intervenes with the driving action to comfortably keep the vehicle at the approximate center of the lane. An emergency lane keep assist system (ELKAS) on the other hand, only intervenes to pull the vehicle back inside the lane if an unintentional drift is detected. In this case, the actuation concerns the safety, thus it may not always feel comfortable. There are also passive safety systems available which do not actively take part in vehicle control, but intervene by audio-visual and haptic warnings. Figure 1-1 illustrates the basic functional principles of the lateral assist systems.

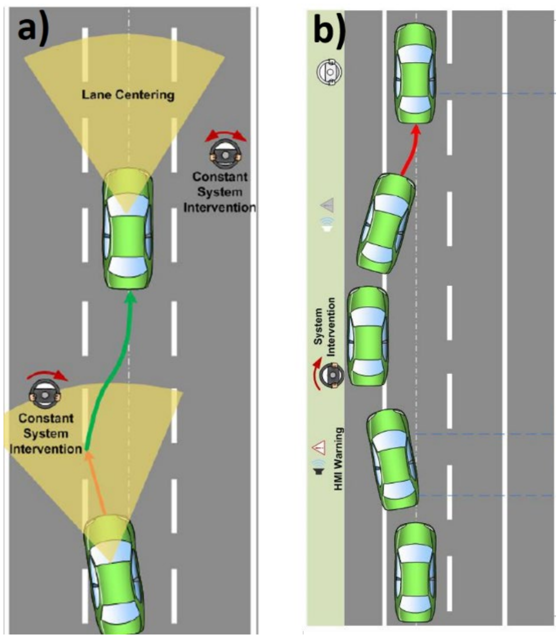

Figure 1-1: Illustration of the typical lateral assist functions. a) lane keep assist, b) emergency lane keeping

Obviously, lateral assist systems have to perceive the environment in order to detect the lane boundaries and locate the ego vehicle within. The most common sensor for this task is a front camera, while solutions combined with RADAR and LIDAR sensors also exist. The status of the lateral assist systems is communicated with the driver via the HMI and the driver can always take over the control from the lateral assist functions. An example is provided in Figure 1-2.

Figure 1-2: An illustration of a HMI1 where the driver is informed about lateral assist status. The green lines indicate that the lane markers are detected and the system can be activated [3].

1.2. Project Context

Valeo Schalter und Sensoren GmbH is one of the leading automotive suppliers, supporting global OEM's in various domains. Bietigheim based Comfort and Driving Assistance Systems Division of Valeo is the branch where the ADAS solutions are developed and commercialized for the partners or prospective projects. Currently, Valeo already owns proven lateral centering and adaptive cruise control systems. The automation level of the current functionalities falls under SAE Level 1 and Level 2 systems [4], as configurations with only longitudinal control, only lateral control or combined control are available. An illustration of the SAE driving automation levels is provided in Figure 1-3.

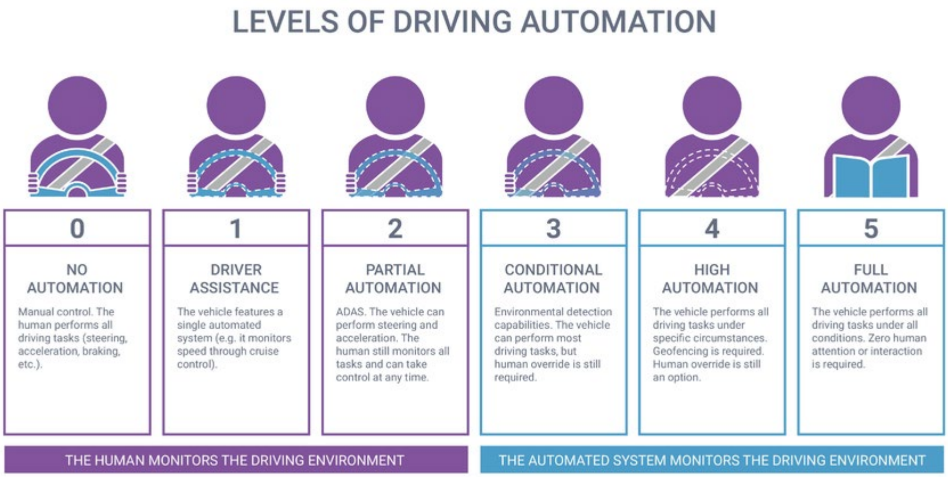

Figure 1-3: SAE automated driving levels according SAE International J3016 [5]

To explore the latest technologic advancements for improving the existing solutions of Valeo, a collaboration with TU/e was initiated in the year 2018, and two PDEng projects were accomplished. These projects separately focused on the longitudinal and lateral control systems and utilization of the map data for ADAS applications was one of the main objectives [6][7]. Since the performance of any ADAS function is highly dependent on the extent and accuracy of the environmental perception, Valeo aims to strengthen and widen their sensor range by exploring feasible alternatives that would provide an additional input to the on-hand perception units. This motivation lead Valeo to further invest on map technologies by searching ways to integrate the advantages brought by map data, such as the extended driving horizon that exceeds the detection range of the onboard sensors [8]. Consequently, this project was initiated, aiming to go deeper with the map-based strategies to enhance the existing lateral assist capabilities while also utilizing the experience gained during the previous PDEng projects.

Amongst the lateral vehicle control approaches, target following with trajectory tracking is also an important method that can enable automated driving for handling complex scenarios [9]. Hence, Valeo desires to explore the possible outcomes of such a strategy, since the target detection for longitudinal control is already an existing Valeo functionality, requiring no additional sensor investment. Accordingly, target following strategies for lateral control purposes were also involved in the context, aiming to develop combined solutions with the map-based strategies.

In collaboration with HERE Maps [10], the ADASIS platform [11] is the provider of the ADASRP tool, which is to be utilized as the map software throughout the project. Briefly, ADASIS is a forum that is formed by unison of various automotive OEMs and map database suppliers. ADASRP tool is the product of this collaborative development platform, and it has the capability of constructing an electronic horizon that provides information about the road ahead. The mentioned electronic horizon constitutes the basis of the map-based strategies that is to be develop in the context of this project.

1.3. Project Goals

The aim of the project is to improve lateral assist systems, accordingly current lane keeping functionalities are taken as the baseline. The specific scenarios in which the current functionalities cannot succeed are focused in order to define the system use cases. Consequently, the development is focused on the non-highway scenarios that are challenging for the front camera unit, since these scenarios provide a good measure about for how much the existing system can be improved. The resultant project goals that are shaped to their final forms as follows:

- Utilization of the map's electronic horizon data aiming to generate an alternative lane boundary representation that supports Valeo's existing environmental perception units. This strategy is named as "map-based lane construction".
- Development of target following strategies for lateral control purposes, in combination with the map-based strategies where the target vehicle assessment is based upon the map-based lane construction. This strategy is named as "target-based path generation".
- Application of the developed strategies to specific non-highway scenarios in which the system performance can be measured. After necessary elicitations, the use case scenarios are defined as below:
    - Simple intersections and junctions, with a nearly straight exit
    - Highway entry and exits

The visualization of the project goals can be found in Figure 1-4.

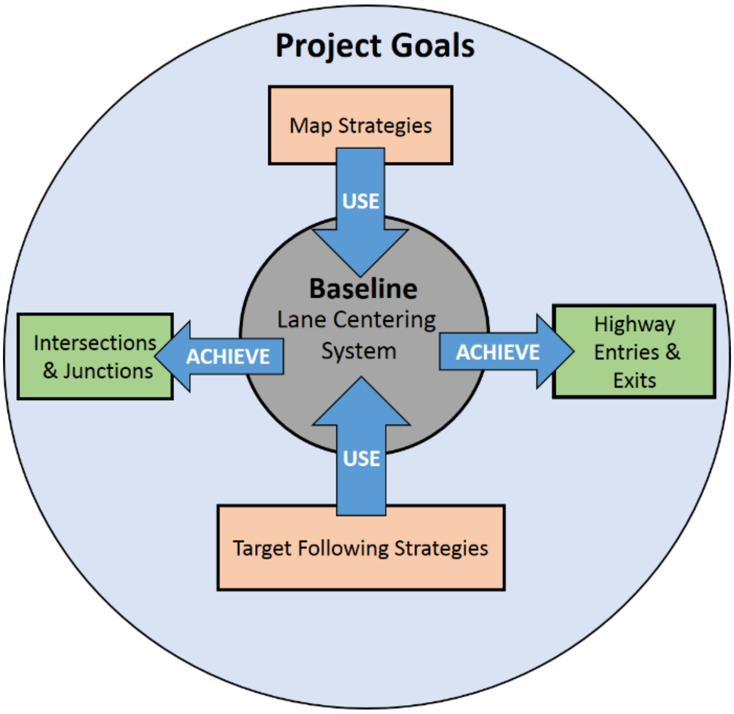

Figure 1-4: The broad frame of the project goal as defined during the initial phase of the project.

Under the definition of the project goals, the research question can finally be framed as:

"How can the map data be integrated to camera-based lane centering systems in order to handle specific non-highway scenarios, and how can it be combined with further lateral control strategies such as target following?"

1.4. Problem Analysis and Solution Concept

Lateral control in non-highway conditions can be challenging in many different scenarios for the front-camera-only assist systems. Consequently, the problem domain was narrowed down to specific cases which are commonly encountered in real-life traffic conditions. In the context of the project, two different scenarios are analyzed, as given in the following sections.

1.4.1. The Highway Exit – Entry Problem

One of the commonly experienced cases where the camera based lateral assist functions do not perform well, occurs when the ego vehicle takes a highway exit or entry with a high curvature with a value of $-0.01 < \kappa < 0.01$. In this particular situation, the camera detection may be lost due to the field of view limitations, or the overlapping lane marker vision. Consequently, the detection suffers from losing its reliability at the beginning of the exit, and then can be totally lost as the vehicle proceeds within the exit lane, as illustrated in Figure 1-5a). On the contrary, digital maps do not rely on visuals sensor for detection of the driving horizon, hence as long as the ego vehicle is sufficiently located within the ego lane, the radius information along the path would be accurate. A solution can be shaped upon this capability, by increasing the reliability of the camera detection, and even extending the detection range. Illustration is provided in Figure 1-5 b).

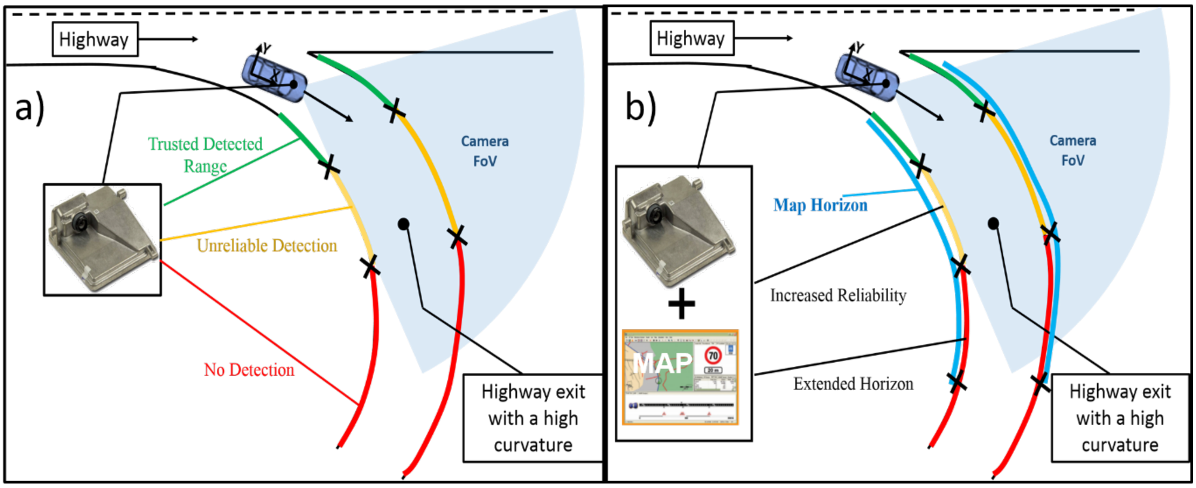

Figure 1-5: a) Illustration of the highway exit situation where the front camera lane detection loses reliability and cannot perceive the high curvature road shape. The green markings are for the trusted detection, yellow is for the unreliable detection and the red is for no detection. b) Illustration of the enhanced detection by introducing the map horizon (blue) to the system. The coverage of the map horizon can increase the reliability and can even extend the detection range.

1.4.2. The Intersection Problem

One another frequently encountered problem for the lateral assist systems is the intersections, where the lane markers have the discontinuity. In this case, the assist function can get suspended and before the suspension, the curved lane marker connection to the right turn can misguide the camera, which may result in a false steering action. This phenomenon is illustrated in Figure 1-6 a). As a remedy, the map software can be utilized for its electronic horizon for lane continuity, and junction detection for situation assessment. Consequently, the preceding vehicle can be evaluated as a lateral control target. If positively assessed by the map, the preceding vehicle can be followed until the intersection exit without disabling the lateral assist functionality. The concept is visualized in Figure 1-6 b)

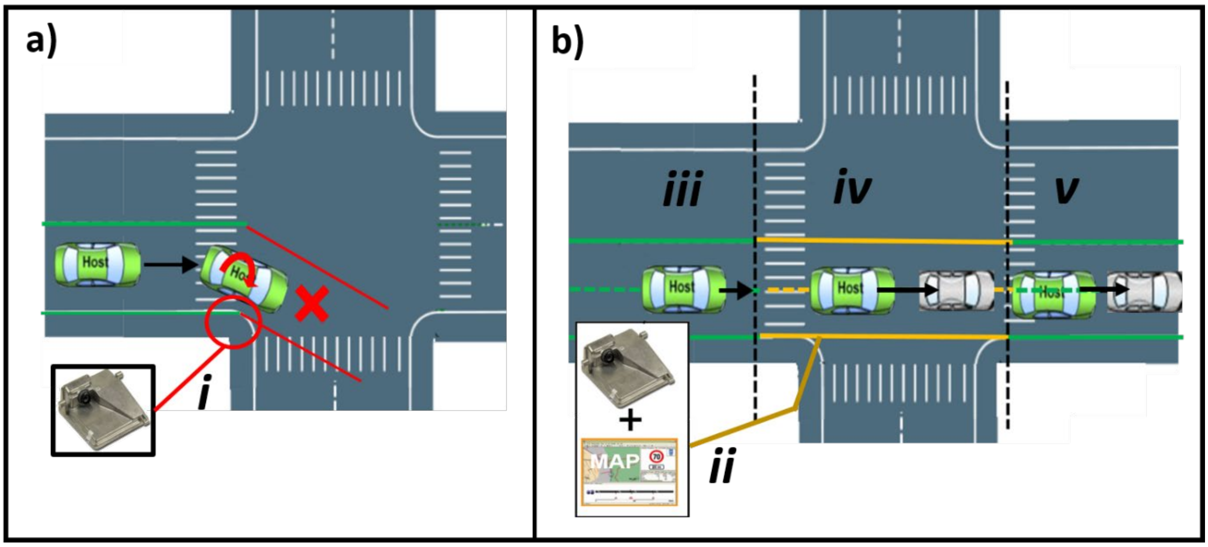

Figure 1-6: a) Illustration of the camera misdetection at the entrance of the intersection. i) shows how the lane marker connection to the right turn causes the camera to generate a false reference that results in a undesired steering maneuver, b) Illustration of the identical intersection case where the map data is utilized to generate the missing lane boundary information during the crossing, as shown in *ii*. Ideally, the map initiates the construction at state *iii* before entering the intersection to prevent *i* from happening. The constructed lane boundaries can be

used to assess a preceding vehicle to follow during the crossing as shown in *iv.* At *v,* the lane markers are recovered and the camera functions are enabled.

1.5. Feasibility Analysis and Scope Definition

The project has to be handled with all means of the design process, where the conceptual design, system engineering, system development, modelling and coding, validation and project management has to be performed with a single main responsible. Accordingly, a definitive scope identification has to be agreed and limitations of the project has to be set by a feasibility analysis upfront the design activities. Consequently, the following activities are involved within project scope:

- System Engineering
  - Stakeholder analysis
  - Use case determination
  - Requirements elicitation
- System Architecture
- System Design
  - Development of "Map Based Lane Constructor" module on Simulink platform by using the ADASRP and ADTF input.
  - Development of target following strategies and implementation in combination with map solution.
  - Arbitration logic for highway exit and junction scenarios.
  - Development of a visualization tool to monitor system results running on simulated or recorded vehicle data.
- Validation
  - Validation of the system by pseudo vehicle tests, where the recorded test data is used as input for measuring the system performance.

The limitations of the project due to various restrictions are subsequently identified:

- The sensor scope is limited by the front camera only.
- User interface design is not considered.
- Although the developed solutions can potentially be applied to other scenarios, only the highway exit and junction scenarios are on focus.
- The ADASRP V3 is not available, hence the development is based on ADASRP V2. Consequently, HD map features cannot be utilized.
- The performance issues of the ADASRP will not be fixed and the software will be used as it is.
- Although initially discussed, lane construction based on road edges (grass, rail, etc.) is removed from the scope.
- The lateral controller will not be modified. In case of an integration study in the future, the reference change between arbitration modes is assumed to be handled by the controller with a prospective future work.
- The integration to Valeo platform is considered as a future work. Accordingly, the validation will be performed in a simulated environment.

1.6. Project Planning

The interval between the official kick-off and the project finish date was nine and a half months, which can be regarded as a challenging schedule compared to the project scope and expected deliverables. Thus, an effective and dynamic project management strategy became essential in order to adapt to the evolving environment that were rapidly affecting the task breakdown and the scope definition.

The planning phase was initiated by clarifying the problem definition, and narrowing it down to a manageable level by the systems engineering approach where the problem was analyzed from the stakeholders' point of view. The design system which had to respond to the needs of the stake-holders was then handled by defining appropriate use cases and the associated requirements per them. The initial scope of the project was identified in a broad manner, and then was iteratively re-defined during the important milestones by certain feasibility analysis. Trade-offs were made, and some objectives had to be dropped in sake of increasing the quality of the ones with higher priority. For instance, lane identification using the road edges such as curbs and side rails were involved in the scope at the beginning, but then removed from the scope to allocate more time on the map and target following related strategies. Validation on car was also planned at first, however schedule related issues lead the system to be verified with the trace data, which is recorded during the real-life driving sessions.

The timing was controlled over a Gantt chart to identify the important tasks, their classification and reflection over the schedule with the predefined milestones. However, instead of sticking with a strict plan, the chart was periodically updated due to the changing environment and demands, according to the decisions and agreements made during the meetings. The last stage of the project schedule is presented in Figure 1-7 with a Gantt chart.

1.7. Conclusion

The objective of the project was divided into two main titles as listed below:

- Integration of the digital map data to the camera-based lateral assist system in order to enhance the functionality in specific scenarios.
- Development of target following strategies for lateral control purposes.

Consequently, the main objectives defined at the beginning of the project were achieved and strategies based upon the map technology and target following methods were applied on the agreed use cases, by the simulations using the real-life driving data. The results indicated the prospective success of such a system that is further developed following the presented methodology. As a conclusion, it can be stated that the research question is answered by the proof of concept, where it was shown that map-based strategies can aid lateral assist functions by enhancing the camera detection and also enabling other strategies like target following.

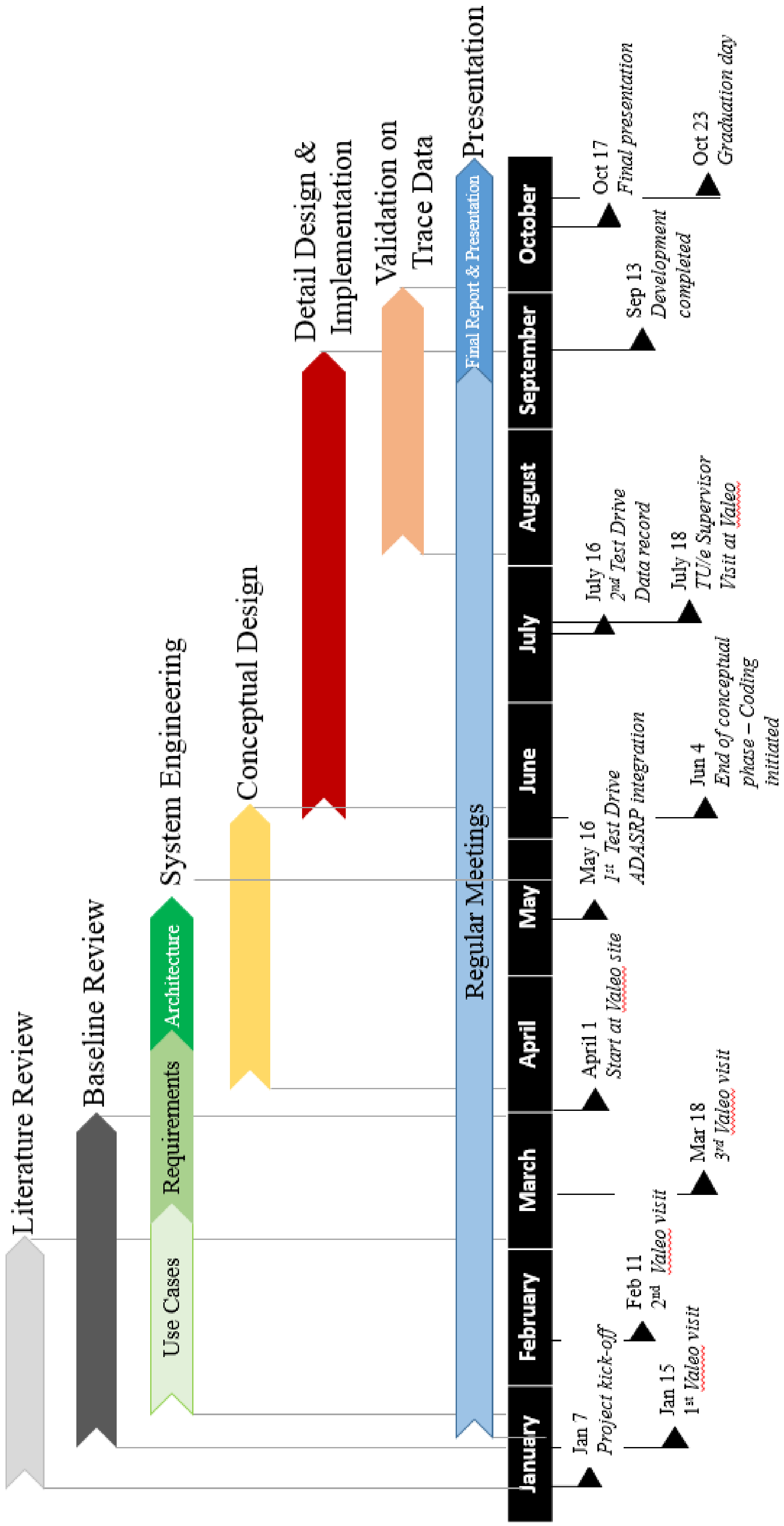

Figure1-7: The project schedule

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