Politecnico di Torino

Master of Science in Computer Engineering

Tesi di Laurea Magistrale

Software Defined Vehicle with AWS Services

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Anno Accademico 2023-2024

Summary

In the dynamic landscape of the automotive industry, the imperative to equip vehicles with flexible hardware and upgradable software is a key priority, both in terms of efficiency and ensuring the safety of the vehicle itself.

Cloud technology addresses these needs by providing virtually unlimited resources to ensure reliability and security through cost-effective pay-per-use services for companies.

The work of this project, carried out in collaboration with the company Storm Reply, is dedicated to the implementation of a platform focused on the Software Defined Vehicle (SDV) paradigm, leveraging the comprehensive services provided by Amazon Web Services (AWS) and aiming to create a convergence point between the edge device and the cloud environment, ensuring an advanced and secure experience for the end user.

A Software Defined Vehicle is characterised as a vehicle that primarily or entirely manages its operations, incorporates additional functionality and enables new features through software. The concept is based on the synergistic use of cloud technology for server-side operations such as updates, coupled with general-purpose hardware for vehicle-side functions. This technological integration significantly enhances vehicle security from multiple perspectives, including Human Safety Critical Security and Intrinsic Software Security.

The thesis starts with an introduction on the objectives of the project and goes on to provide a broad overview of the state of the art methodologies currently used in the cloud space, specifically related to the automotive industry.

Secondly, the entire stack for the development, maintenance and deployment of software for connected vehicles is examined in detail, along with techniques for secure communication between the vehicle and the cloud.

Finally, a real-world project is examined, in which a sample infrastructure for maintaining and deploying code, as well as analysing data from the simulated vehicle, was created using AWS Cloud Services.

Acknowledgements

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Chapter 1

Introduction

1.1 Context

The automotive industry stands out as one of the fastest-growing sectors, playing a significant role as both an employer and an investor in research and development; at the same time, it represents one of the most crucial domains for the European Union's economy. As reported in the article (Source: [1]), in 2015, 21 million motor vehicles of all types were produced in Europe, representing a 23% share in the global production of more than 90 million units.

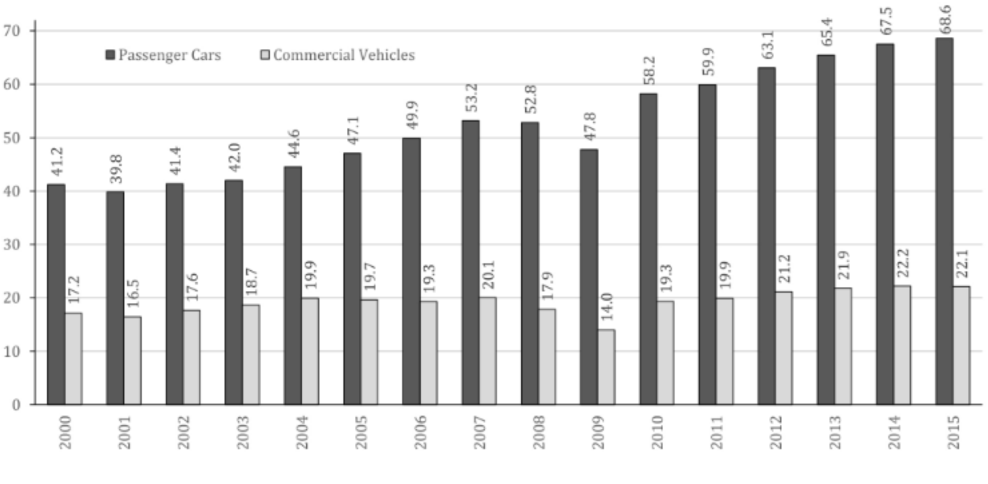

Figure 1.1. World automobile production in million vehicles [1]

In the evolving landscape of automotive technology, the imperative for automotive companies extends beyond the traditional realms of mechanical engineering to encompass a crucial reliance on both software and hardware components for vehicle construction. A glimpse into the intricate web of modern cars, as illustrated in Figure 1.2, reveals a mosaic of hundreds of distinct processors interfacing at various levels, earning contemporary vehicles the moniker of "Computers on wheels."

However, the proliferation of processors within vehicles, orchestrating communication to manage diverse components, presents a formidable challenge; each component often integrates a processor with unique logics, diverging from the logics

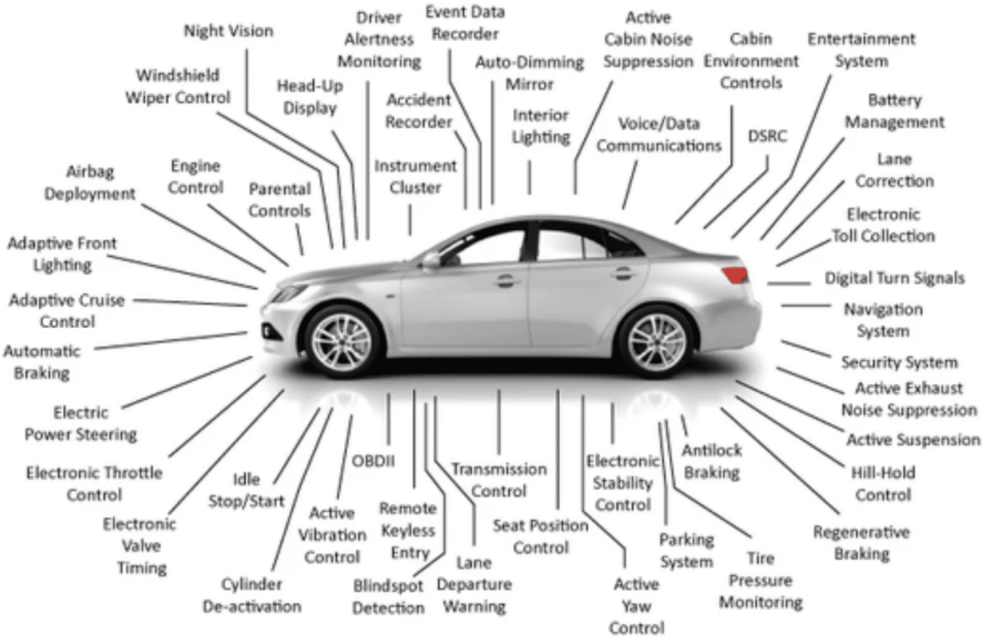

Figure 1.2. An incomplete overview of computers in a modern car Source: [2]

embedded in processors of other components. Complicating matters further, these components are frequently supplied by companies with proprietary management logics, not readily accessible to the automotive companies themselves.

In addressing this intricate scenario, the transformative concept of a Software Defined Vehicle (SDV) comes to the forefront. Defined as "any vehicle that manages its operations, adds functionality, and enables new features primarily or entirely through software" (Source: [5]), the notion of SDV offers a comprehensive solution to the challenges posed by the intricate interplay of software and hardware in modern vehicles.

Effectively navigating the development of SDV technology necessitates a collaborative approach across diverse companies, particularly in the realms of hardware and cloud computing. This collaborative synergy is exemplified in the realization of our project, made possible through the partnership with Storm Reply.

1.2 Company

Leveraging extensive experience in the cloud industry and fostering deep-rooted relationships within the automotive sector, Storm Reply stands out as the ideal choice to lead the project discussed in this thesis. A key player in the Reply group, Storm Reply specializes in designing and implementing innovative Cloud-based solutions and services [6].

With a diverse clientele spanning various sectors, notably the automotive industry, the company's expertise played a pivotal role in comprehensively understanding the project's context and internal dynamics. This profound knowledge served as the cornerstone for developing a tangible exemplification of the infrastructure.

Figure 1.3. Logo of the partenr company of the project

A point of pride for Storm Reply is its recognition as an Amazon Web Services (AWS) Premier Consulting Partner since 2014, ranking among the top Amazon Partners globally. This distinctive characteristic underscores the decision to develop the infrastructure using Amazon Web Services.

According to the official AWS description page [7] the AWS Cloud spans 102 Availability Zones within 32 geographic Regions around the world and servs 245 countries and territories. With millions of active customers and tens of thousands of partners globally, AWS has the largest and most dynamic ecosystem. AWS is evaluated as a Leader in the 2022 Gartner Magic Quadrant for Cloud Infrastructure and Platform Services, placed highest in Ability to Execute axis of measurement among the top 8 vendors named in the report.

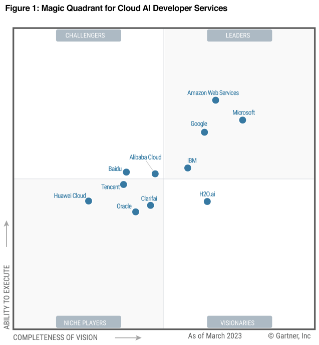

Figure 1.4. Here are a series of market research reports published by IT consulting firm Gartner that rely on proprietary qualitative data analysis methods to demonstrate market trends, such as direction, maturity and participants. Source: [3]

The infrastructure exhibits several key attributes contributing to its robustness and efficiency:

- **Security:** The infrastructure undergoes 24/7 monitoring to ensure the confidentiality, integrity, and availability of data. All data flowing across the AWS global network is automatically encrypted at the physical layer before leaving secured facilities.
- **Availability:** To ensure high availability and isolate potential issues, applications can be partitioned across multiple AZs (Availability Zones) within the same region, creating fully isolated infrastructure partitions.
- **Performance:** AWS Regions offer low latency, low packet loss, and high overall network quality. This is achieved through a fully redundant 100 GbE fiber network backbone, often providing terabits of capacity between Regions.

- **Scalability:** The AWS Global Infrastructure allows companies to take advantage of the virtually infinite scalability of the cloud. This enables customers to provision resources based on actual needs, with the ability to instantly scale up or down according to business requirements.

- **Flexibility:** The AWS Global Infrastructure provides flexibility in choosing where and how workloads are run, whether globally, with single-digit millisecond latencies, or on-premises.

- **Global Footprint:** AWS boasts the largest global infrastructure footprint, continually expanding at a significant rate.

1.3 Thesis Goal

In the automotive context, the use of Software Defined Vehicle (SDV) plays a crucial role in terms of costs, innovation, and safety. The goal of the thesis intertwine with the opportunities provided by Software Defined Vehicle technology, addressing the primary challenge of managing the current difficulties associated with the presence of various specialized hardware platforms on the same vehicle.

The central objective of this thesis is to propose a Software Defined Vehicle solution capable of eliminating various phases of the software production pipeline. This would result in significant time and cost savings, enabling the investment of these resources in other sectors. Since, by definition, a Software Defined Vehicle is characterized by the ability to undergo software updates dynamically and flexibly, this solution offers significant security advantages in various aspects:

1. Human Safety Critical Security: From the moment that a vehicle can be classified as safety critical (as it is reported in the standard ISO 26262-1:2018 of the ISO society where is said that ”safety is one of the key issues in the development of road vehicles” Source: [8]), the elimination of software vulnerabilities related to the vehicle's systems is crucial for the overall safety of the vehicle itself.

2. Intrinsic Software Security: This approach allows for the prevention and resolution of vulnerabilities unknown at the time of software design, contributing to ensuring a high standard of security.

Consequently, the use of Software Defined Vehicle aims to completely separate software and hardware, allowing the production of high-level software on entirely generalized hardware systems. This results in significant savings in terms of time and money for hardware production, along with providing an advantage in terms of security due to the simplification of software.

For example, as demonstrated by NIST in the research on the Analysis Of The Impact Of Software Complexity (Source: [9]), the increase in software complexity in different cases results in less analyzable programs. In some instances, the same vulnerability analysis tool may detect vulnerabilities, while in others, analyzing the same code, it may not.

From a practical standpoint, the project's goal is to provide, through the use of AWS services, a cloud infrastructure capable of managing the Software Defined Vehicle both in terms of software production and data analysis.

Chapter 2

State-of-the-Art Analysis

The following chapter constitutes an in-depth exploration of current technologies and methodologies within the automotive industry, with a specific focus on the complexity of vehicular software development. Firstly, the current automotive landscape will be examined, providing a detailed insight into challenges associated with software development in vehicles.

Subsequently, through meticulous analysis of scientific publications, technical reports, and practical implementations, the chapter delves into the radical transformation of the automotive sector facilitated by the concept of Software Defined Vehicle (SDV). This technology, crucial for technological progress and vehicular safety, will be explored from various perspectives. Particularly, the synergy between Cloud, software, and hardware will be investigated, highlighting solutions proposed by major industry players and analyzing their applications, benefits, and limitations.

The objective is to offer a comprehensive overview of current dynamics, emphasizing the pivotal role of SDV in the evolution of the automotive industry.

2.1 Current Automotive Software Development

In the past, the automotive industry advanced primarily through the development of technologies in mechanical engineering, focusing on perfecting combustion engines. Nowadays, the paradigm has radically changed due to multiple factors, including electrification, automation, shared mobility, and connected mobility.

Software technology development in the automotive field can be metaphorically compared to what has happened in smartphone development, as highlighted in the manifesto document regarding Bosch's Software Defined Vehicle (SDV) [10].

The ultimate goal is to achieve simple and user-friendly devices that fully meet the user's needs. Currently, many customers express dissatisfaction because their cars do not offer the same functionality and ease of use common in smartphones. Many ask: Why can't my $50,000 car perform the same tasks as my $300 smartphone?

A key difference between the automotive and smartphone industries is the level of complexity, which brings with it a number of issues.

2.1.1 difficulties

We can analyse in depth the problems of the current automotive software that is being developed via 4 main difficulties:

- Specialized Hardware: Today's vehicles are still complex systems of systems. Each subsystem in a car, from brakes to transmission, is a complex entity, supplied by a different manufacturer and integrated with a unique software architecture. The level of complexity and the need for seamless interoperability between systems far exceeds that of today's smartphones.
- Time: The software production pipeline involves many development and testing steps with a not inconsiderable amount of time spent on each one. This is greatly increased by the presence of different components, so development time must be considered for each different unit of the system.
- Cost: The complexity of the software systems in vehicles entails very high costs, aggravated by the fact that the test phase is often carried out directly on the boards (for hardware requirements), which means a much longer production process, especially in the event of errors.

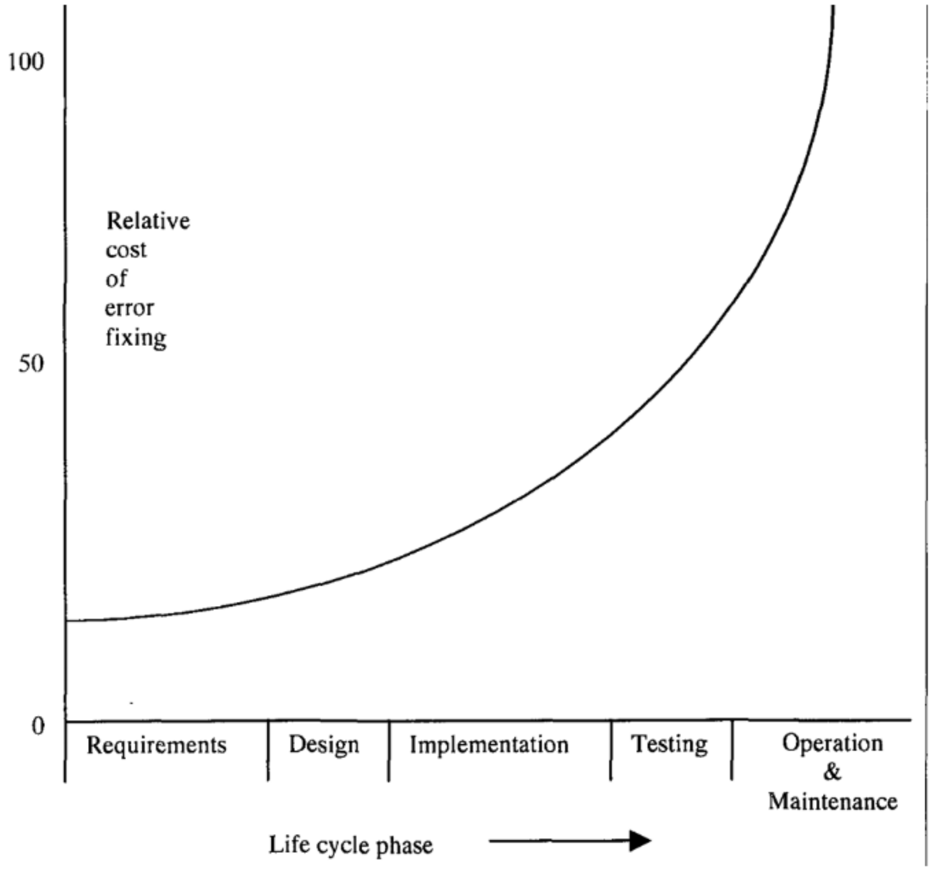

Figure 2.1. Cost of fixing errors increases in later phases of the life cycle [4]

- Human Safety Security: Automotive embedded software must meet stringent reliability and security requirements, while delivering performance and a reasonable memory footprint. To develop automotive embedded software, you need the right tools that meet safety and security standards to evaluate, prototype and test your software.

What lessons can be drawn from the study of barriers that can be applied to the vehicle lifecycle? Historically, the vehicle lifecycle has been characterised by the simultaneous production and deployment of tightly integrated hardware and software. Once the vehicle was in the hands of the consumer, its characteristics remained largely unchanged until the end of its life. However, the SDV paradigm introduces the possibility of decoupling hardware and software release dates - a prerequisite for adopting a digital-first approach. This approach brings the design and virtual validation of the digital vehicle experience to the forefront of the lifecycle.

There is also a need to apply the digital-first concept, which means that new ideas for the vehicle experience are first explored in virtual environments to ensure early user feedback, long before any custom hardware needs to be developed or a physical test vehicle is available. Digital first is the application of design thinking and lean startup principles, originally rooted in internet culture, to the tangible realm of automotive development.

2.2 Introduction to Software Defined Vehicle

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Bibliography

[1] Vošta and Kocourek, “Competitiveness of the european automobile industry in the global context.” *Politics in Central Europe*, vol. 13, no. 1, pp. 69–89, 2017. [Online]. Available: https://www.politicsincentraleurope.eu/documents/file/PCE_2017_1_13.pdf#page=71

[2] R. Saracco, “Sdv: Software defined vehicles,” 2021. [Online]. Available: https://cmte.ieee.org/futuredirections/2022/11/01/sdv-software-defined-vehicles/

[3] J. Scheibmeir, S. Sicular, A. Batchu, M. Fang, V. Baker, and F. O’Connor, “Magic quadrant for cloud ai developer services,” *Gartner*, 2023. [Online]. Available: https://pages.awscloud.com/Gartner-Magic-Quadrant-for-Cloud-AI-Developer-Services.html?trk=d59e704f-4f30-4d43-8902-eb63c3692af4&sc_channel=el

[4] M. KARLSSON and L. SCHÖNBECK, “Department of technology management and economics,” *CHALMERS UNIVERSITY OF TECHNOLOGY*, p. 11, 2018. [Online]. Available: https://odr.chalmers.se/server/api/core/bitstreams/077c3440-c033-418e-92ed-eda5dd638c5f/content

[5] B. QNX, “What is a software-defined vehicle?” *Software-Defined Vehicles*, 2024. [Online]. Available: https://blackberry.qnx.com/en/ultimate-guides/software-defined-vehicle

[6] S. Reply, “Who we are,” 2024. [Online]. Available: https://www.reply.com/storm-reply/en/

[7] AWS, “Aws global infrastructure,” *About-aws*, 2024. [Online]. Available: https://aws.amazon.com/about-aws/global-infrastructure/

[8] I. Society, “Functional safety,” *ISO 26262-1:2018 Road vehicles*, no. 2, 2018. [Online]. Available: https://www.iso.org/obp/ui/en/#iso:std:68383:en

[9] C. D. D. O. E. N. Fong and P. E. Black, “Impact of code complexity on software analysis,” *NIST IR*, vol. 8165, no. upd1, pp. 1–12, 2017. [Online]. Available: https://nvlpubs.nist.gov/nistpubs/ir/2017/NIST.IR.8165.pdf

[10] D. Slama, A. Nonnenmacher, and T. Irawan, “The software-defined vehicle,” *A Digital-First Approach to Creating Next-Generation Experiences*, pp. 1–6, 2023. [Online]. Available: https://www.bosch-mobility.com/media/global/mobility-topics/mobility-topics/software-defined-vehicle/