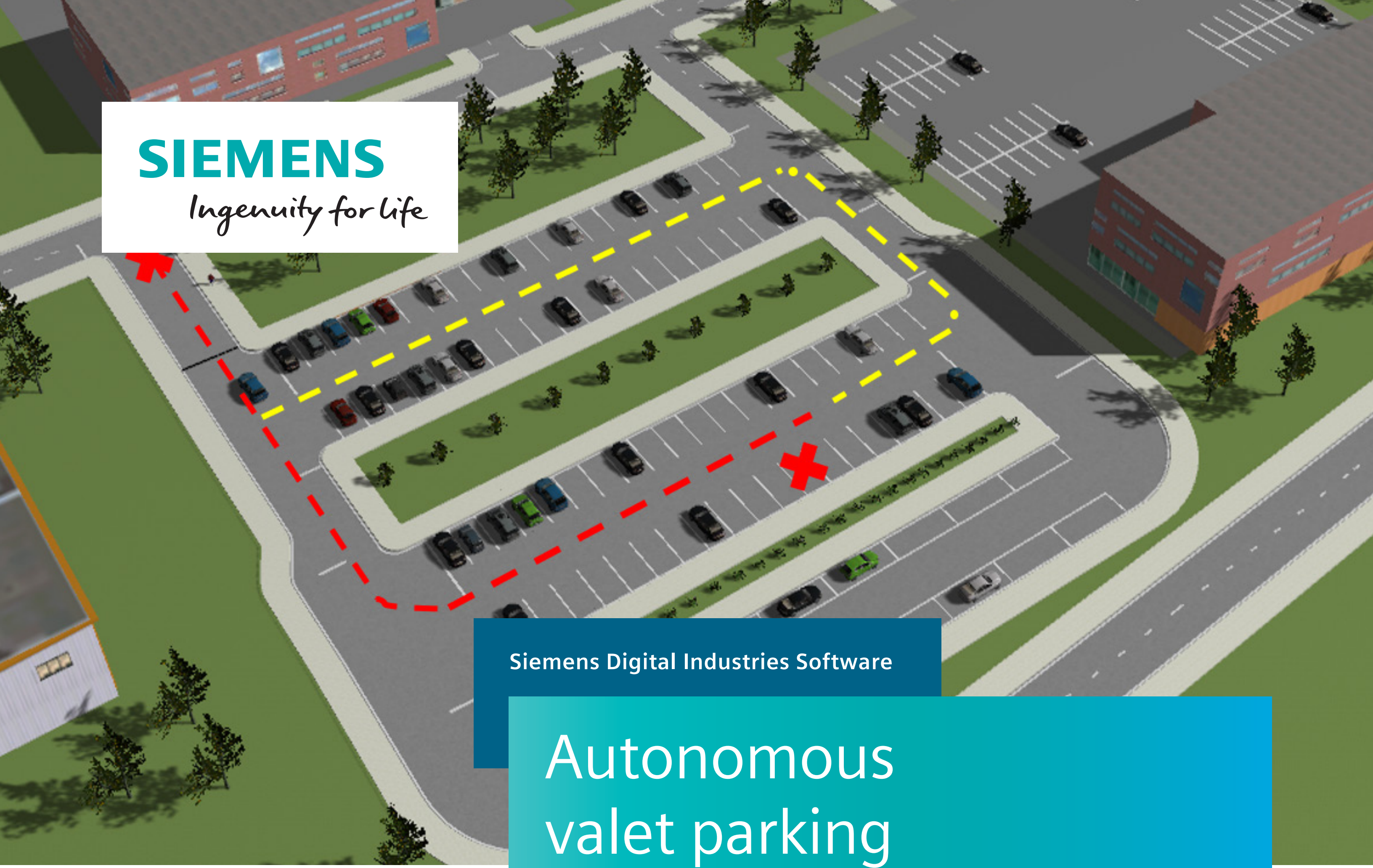


Siemens Digital Industries Software

Autonomous valet parking

Using simulation and testing to develop safe and robust systems and algorithms

Executive summary

This paper discusses the development of autonomous valet parking (AVP) systems and the challenges of defining an exhaustive set of test scenarios and validate AVP systems in all identified conditions. The paper also highlights some critical requirements for the development of autonomous valet parking features.

Introduction

Autonomous valet parking systems in passenger cars will be among the first "driverless" vehicle applications that reach the market. The expansion of these systems will help to reduce congestion, optimize the use of available parking spaces and improve fuel economy and driver convenience.

This evolution of AVP systems requires managing safety and ensuring a robust solution, dealing with complex traffic situations and considering varying conditions due to narrow parking spaces, obstacles, vehicle dynamics, weather and other disturbances.

Based on experience from funded research and projects with both OEMs and Tier-1 suppliers, this paper highlights some of the critical requirements for the development of an autonomous valet parking feature:

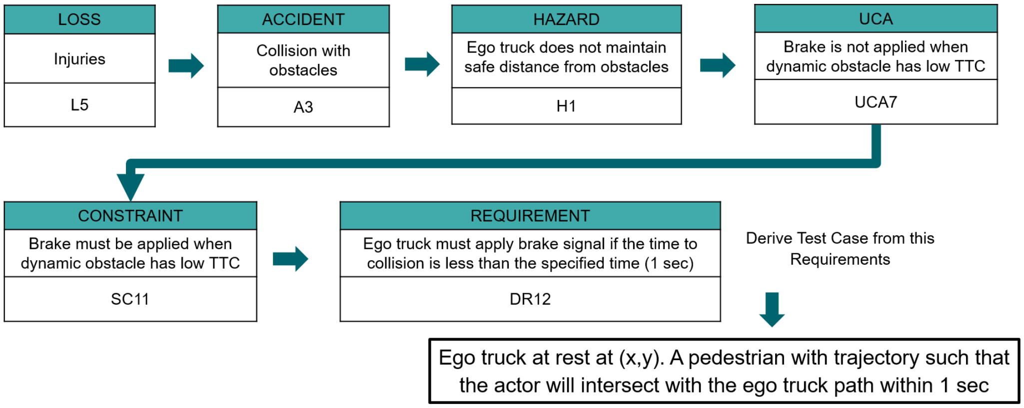
- An accurate virtual framework to test and verify the system and algorithms, and identify a reduced set of critical scenarios for further physical verification
- Integration in the framework of the physical system and vehicle as they become available
- A continuous link to functional, performance, and safety requirements.

Requirements and test scenarios

The definition of a complete set of test scenarios to validate the AVP system is needed. These scenarios will strongly depend on the environment (parking lot, warehouse, end of line of vehicle manufacturing, etc.) which will drive the requirements of the system as several use cases.

Scenarios include both nominal cases and failure cases (for example, failure of a sensor or noise on a sensor signal). Initial scenarios are directly derived from the requirements and the expected scenarios within which the system will have to successfully operate. For each scenario, a broad range of conditions and parameters are considered. For instance, when performing a parking maneuver, these include: 1) incremental starting and end positions of the ego vehicle; 2) vehicle orientation (for example, being parallel or making various angles with the road direction, oriented on the left or right side of the parking spot); 3) introduction of other actors (for example, pedestrians, vehicles). Each scenario also requires a definition of what the vehicle is expected to do in different scenario variants (for example, stop and wait while a pedestrian is crossing the street).

The ISO 26262 standard, covering the functional safety of electrical and/or electronic systems in vehicles, supports the definition of safety-relevant conditions, however it



STPA addresses external events and internal process control actions that may result in potential hazards to be considered. The methodology derives safety requirements and identifies test cases in a structured way.

does not fully address higher levels of autonomy as is the case for AVP. The AVP system may create a hazardous situation under non-faulted conditions that may result in harm to other actors. This gap can be addressed by applying ISO/PAS 21448, safety of the intended functionality (SOTIF) analysis to ensure there are no "missing technical safety requirements" that were not captured through the hazard analysis and risk assessment (HARA) performed as part of ISO 262626 Part 3. System-theoretic process analysis (STPA) addresses external events and internal process control actions that may result in identifying potential hazards ("known-unsafe" scenarios) to be considered. The STPA methodology derives safety requirements and identifies test cases in a structured way. The result is an enrichment of the initial set of safety requirements and test cases that may not have been identified using traditional hazard analysis techniques.

Different sources can be used to identify relevant scenarios for the AVP verification and validation, including existing standards, public literature, real driving data, accident databases and others. The test case generation process is iterative and recursive: scenarios need to be modified throughout the development of the system. Using a virtual framework, these cases are tested for many combinations of parameters. The testing enables identification of the most critical combinations or instances of a given scenario in which the control strategy fails. This methodology, based on numerical optimization (using HEEDS™ design exploration and optimization), and developed by Siemens engineering team, allows fine-tuning of the control strategy, focusing on the most relevant cases.

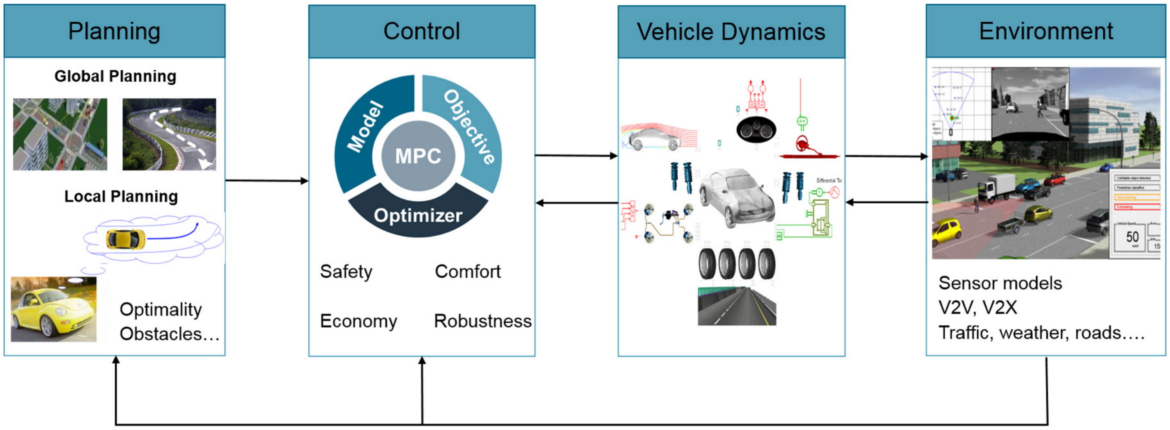
Virtual framework

The virtual framework helps verify the system performance in a very large number of test conditions.

The framework enables users to:

- Assess the set of sensors (type, number, location) for an accurate identification of the driving scene based on machine learning algorithms
- Check the behavior of the system in real-world driving conditions
- Test and verify the control strategy and algorithms
- Identify a manageable subset of critical scenarios for the physical verification and validation of the system

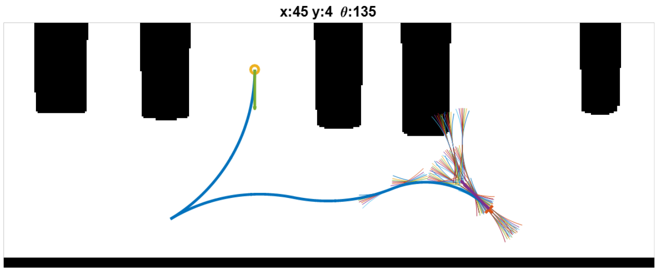
Siemens' Simcenter™ Engineering and Consulting services has applied this framework in previous and current projects on advanced driver assistance systems (ADAS) and autonomous vehicle developments. Models of sufficient fidelity are required to ensure a realistic representation of the vehicle, the AVP system and environment. Vehicle dynamics should be included, as it affects the



The virtual framework helps verify the system performance in a very large number of test conditions.

performance of the system. Various fidelity levels are possible. In Simcenter™ Amesim™ software, the vehicle is discretized in a limited number of degrees of freedom (for example, 15-DOF). This is a computationally efficient approach that requires the knowledge of the physical parameters of the chassis. If it is not the case, a reverse engineering method has been developed to identify these parameters based on a series of tests performed on a vehicle. The tire is also a critical component and is particularly critical for low-speed parking maneuvers; the Simcenter Tire MF-Swift model provides a suitable solution that can be combined with the Amesim vehicle model. Simcenter™ Prescan360 is the solution chosen to represent the static and dynamic scenarios, and allows sensor models with different levels of fidelity, as well as the definition and management of a large set of scenarios and conditions.

The framework is finalized by interfacing with the control algorithms and allows simulation of real test cases in a virtual environment. Simcenter Engineering has developed perception, path planning and control algorithms for various ADAS and autonomous features. In particular for AVP, a graph-search method such as Hybrid A* successfully finds an appropriate path in most cases. Incorporating an optimization-based method, the proposed graph-search algorithms can be extended to distributed motion planning with several vehicles simultaneously. Collision avoidance in critical cases is solved using model predictive control (MPC) or other model-based control algorithms, which can also be combined with a data-driven approach based on artificial intelligence to learn from experienced drivers and improve control accuracy. Finally, "learning control" has been applied to the case of repetitive scenarios, like home or apartment parking. It has shown to iteratively improve control performance (tracking, time, fuel economy, other performance factors) while formally ensuring safety requirements.

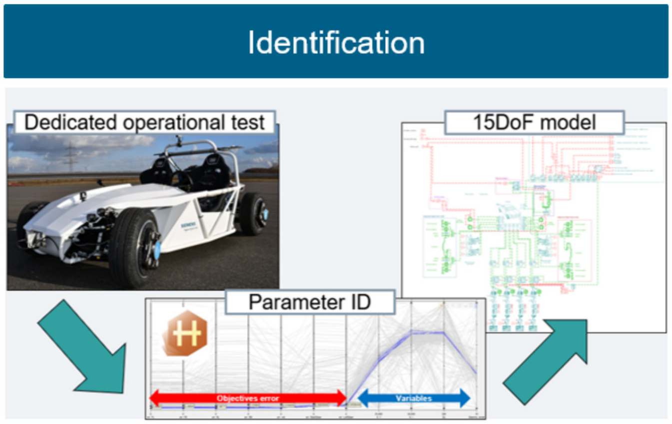


Example of Hybrid A* Path Planning Algorithm to vehicle parking.

Mixed-reality testing

Developers of APV systems must verify that the system can deal with the very complex environments and conditions it will face in operation. This leads to a huge number of test conditions, including various actors, vehicles and pedestrians that cannot all be tested in a physical world. Virtual testing, using the framework described above, is instrumental in managing the verification of the system over a very large number of scenarios. This massive testing can be done on a cluster or in the cloud.

To bridge the gap between virtual and physical testing, the framework is extended to allow a combination of test and simulation in a so-called mixed-reality environment, enabling integration of physical systems as soon as they become available. In the EU-funded ENABLE-S3 project, a mixed-reality experiment has been done in a collaboration between Siemens and Denso to demonstrate this approach. In this setup a real car is driven on an empty parking lot, and virtual actors (static and dynamic vehicles) are introduced based on the virtual framework. The vehicle sensors detect the virtual actors as if they were physically present. This provides a greater flexibility in setting up all kinds of test scenarios, while having the real system on the physical vehicle. Other types of mixed-reality experiments have been conducted by Siemens. Certification authorities are also planning to incorporate mixed-reality tests in the vehicle homologation process.



Process of Vehicle Dynamics model reverse engineering based on operational tests.

Conclusions

This paper discusses the development of AVP and the challenges of defining an exhaustive set of test scenarios and validating the system in all identified conditions. The process of scenario definition is discussed to ensure maximal coverage. A virtual framework is then proposed, to verify the system during its development in many situations through simulation. Finally, the integration of physical and virtual testing into a mixed-reality framework is discussed. This capability allows developers to manage the need for physical verification against such many cases and limit the final validation to a reduced set of down-selected critical cases.

Mixed-reality experiment with a physical vehicle and virtual static/dynamic actors (*).

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