Physics Based Simulation to validate highly automated driving functions

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Abstract

Within the last decades we have been seeing a significant decrease of traffic fatalities even though the traffic density has been increasing. Unfortunately, this trend seems to have been tapering off within the last few years. Notably, the number of incidents involving vulnerable road users like bicyclists and pedestrians is on the rise. *(REF1)* This might partly be because of the distraction of drivers using mobile phones or texting. To ensure safe driving, the proposition is to make driving more automated to mitigate human errors as reasons for traffic fatalities.

Validation is needed to ensure that autonomous driving will be safer than today's traffic. Experts require a safety advantage factor of 100. Although it is not yet clear how to validate autonomous vehicles, experts agree that it will require testing a huge number of road scenarios involving billions of kilometers driven. *(REF2)* What's more, if either the hardware or software configuration of the system is changed, the road tests must be repeated (at least partially). Carrying out real road tests hence becomes unrealistic. The solution ANSYS provides is physics-based driving simulations and virtual validation.

The main advantage of physics-based simulations is that they provide realistic, predictive, repeatable results. However, such simulations are computationally extensive and time-consuming, often requiring cloud computing. The test plan must also be optimized to reduce the number of relevant edge case scenarios and to have an easy method to vary parameters to reduce the simulation time. The use of reduced-order models (ROMs) *(REF3)* and design of experiments (DOE) will be crucial for developing such validation procedures. In this work we explain the roots of ANSYS physics-based simulation for a detailed open loop simulation and propose an architecture for a closed loop simulation re-using the results. We will explain the features of the simulation, show application examples and give an overview on the validation methods and standards used in the automotive industry.

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Keywords: Autonomous Driving, Simulation, Virtual Testing, Perception, Validation, Verification, ISO 26262, SOTIF, PAS 21448

1 Validation concepts for HAD

1.1 Open Loop Simulation

The perception of sensors is crucial for the safe planning of the autonomous vehicle's trajectory. We are particularly interested in avoiding false positive and false negative events *(REF4)*. A false positive perception will detect an obstacle where there is none, which may create a dangerous situation by, for example, performing emergency braking by mistake. In case of a false negative event, the obstacle is not detected (or is detected too late) so that it is not possible to bring the vehicle to a halt.

Clearly, keeping the number of both false positive and false negative events at a minimum is the essential goal of the highly autonomous driving (HAD) perception system. During the initial research and development of HAD systems, one is mainly concerned with the principle functionality and feasibility of the developed solution, but real-life HAD systems must achieve certain safety levels before being recognized by respective state authorities and allowed on public roads. Virtual simulations and validation may help reduce the effort necessary to ensure the required safety in a way that is acceptable to regulators. What's more, simulations may also help engineers and designers validate their decisions at every step, thus facilitating an iterative development process.

However, simulations are only any good when they accurately represent the real world. Therefore, the physics-based approach of ANSYS simulation software is crucial. For HAD, optical perception systems such as cameras and lidars play key roles. Within ANSYS solutions, the simulation and validation of optical systems can be broken down into three steps (see also Figure 1):

1. Component development and detailed optical simulation with ANSYS SPEOS
2. Simulation of the integration pf components into the car using SPEOS
3. System simulation using ANSYS VRXPERIENCE

The first step includes a thorough, in-depth investigation of all optical elements of the device. Due to the physics-based approach to characterization of the materials and taking into account all relevant physical effects occurring when light interacts with those materials, the Monte-Carlo ray tracing employed in SPEOS provides physically correct results. Such physics-based simulations reduce the need to build physical prototypes, and in fact replace real measurement. Various radiometric and photometric investigations, stray light analysis, etc., can help identify important design flaws at early development stages. What is more, since SPEOS is natively integrated in ANSYS Workbench, one can easily carry out parametric studies and optimization. Even better, the integration with Dynardo OptiSLang *(REF5)* provides capabilities for the intelligent design of experiment, sensitivity analysis and, essentially, robust optimization of the developed device.

Once the first design of an optical sensor device is done, the second step — integrating the device into the dedicated HAD system (e.g., a vehicle) — can give valuable insights into the compatibility of the device with the dedicated platform and further guide the development process. The optical sensor test (OST) package of SPEOS is designed specifically for this purpose. With OST, engineers can easily test the performance of the integrated sensor device in various (potentially critical) situations, deduce further development needs and identify potential design flaws. Both Tier 1 and 2 manufacturers and OEMs can profit from this solution. The former get the opportunity to validate their component design in close to real-life conditions. By using simulation results from Step 1 during the integration test, one yields an agile component design workflow. On the other hand, OEMs that normally rely on the information provided by the suppliers, get the opportunity to double-check this information and validate the design of the complete system using SPEOS OST in the same time avoiding physical integration of the components and expensive test-drives.

The third step is system simulation. Once the optical sensor device is developed and optimally integrated into the dedicated platform (system), ANSYS solutions can create a ROM of the device, which is real-time capable and can be tested in the virtual world generated by VRXPERIENCE. The ROM neglects certain “microscale” parameters and effects such as volume scattering, which are not relevant on the “macroscale” of the complete system (HAD vehicle), thus accelerating simulations. VRXPERIENCE simulations are discussed in Section 1.2.

Very often, however, in addition to optical and radiometrical/photometrical analysis, other physical effects must be investigated to get the full picture and see how the system performs in non-nominal conditions. Nominal conditions are the perfect conditions considered in a first development without taking into account mounting tolerances or effects of the environment like temperature on the sensor efficiency. These physical variation effects can be thermal or mechanical, for example. The best-in-class multiphysics simulation portfolio of ANSYS helps engineers achieve their goal by integrating thermal and optical simulations in one productline.

Figure 2 depicts an example workflow of a thermal-optical multiphysics simulation of a lidar device, carried out with SPEOS and ANSYS Mechanical. In the optical simulation, an LED source emits an infrared pulse of light in the direction of the target (vertical bars 5 m in front of the lidar); the light pulse reflects off the target and is gathered and forwarded by the lidar receiver optics to a CCD sensor. In the figure, the received reflected infrared light is simulated for nominal conditions (irradiance map on the left), i.e., with the nominal lens geometry, and for the geometry deformed due to ambient temperature (irradiance map on the right). As can be seen, whereas the design of the device works for the nominal thermal conditions and the vertical bars of the target are clearly distinguishable in the received signal on the left, it is not the case with the signal achieved with deformed lenses on the right. What’s more, both optical and thermal simulations can be coupled in ANSYS Workbench to automate the optical-thermal-optical simulation workflow to do an iterative parametric study and/or optimize the design.

1.2 Closed Loop Simulation

In order to do a closed loop simulation, it is necessary to do fast, in the best case real-time, simulations. Several steps are required to build a closed loop simulation. We can use the results of the open loop simulations to define the positions, orientations and technical characteristics of each sensor, whether it is a radar, a camera or a lidar. However, closed loop simulations also require the setup and simulation of virtual roads, vehicle dynamics and traffic scenarios between the different vehicles of the virtual scene. Additional monitoring of variables of the scene, such as speed, position in the lane or crashes of the ego car are usually also required. Finally, the generation of sensor outputs and eventually the view of the driver are also required for the control flow directing the ego car, generally all in real-time. This is exactly what VRXPERIENCE Driving Simulator Powered by SCANeR® provides.

A simulated sensor output can either be a list of objects or a signal representative of the real sensor output. VRXPERIENCE Driving Simulator Powered by SCANeR provides a list of objects that each sensor can see in its field of view and range. The software user can configure what object can be detected by each sensor (by example, a camera will detect road markings and traffic signs, which cannot be detected by radar; however, radar can provide better information about the speed of the cars in front of the ego car than the camera). A list of objects as sensor outputs are often enough to develop ADAS functions such as lane keeping or adaptive cruise control. But to improve the robustness and to validate the ADAS functions against difficult scenarios (called edge case scenarios), it is necessary to simulate a signal representative of the real sensor output. This would be a raw image for the camera or a time-of-flight image for a lidar.

Using its cosimulation mode, VRXPERIENCE Sensors is able to use the virtual roads and the traffic scenarios created by VRXPERIENCE Driving Simulator Powered by SCANeR. It automatically adds optical properties for camera and lidar simulations, as well as ROMs for radar simulation. Of course, it is not possible to use complete multiphysics descriptions of the sensor models for this purpose. But ROMs can give a physics-based result by reducing the simulation time. VRXPERIENCE is then able to simulate radars, cameras and lidars at the same time, on a single real-time platform.

An important application using a representative sensor output is for hardware-in-the-loop (HiL) simulations. This is a closed loop simulation in which the output of the simulated sensor is injected into a real sensor to test how the algorithm embedded in the sensor processes the raw signal and how the overall ADAS functionality behaves on a number of scenarios. HiL simulations are essential to test the robustness of ADAS features of a vehicle.

An example is the high beam assistant ADAS function. With this function the driver of the car does not need to manually switch between high and low beams, as the car does this automatically. Even better, the lighting system is adapted to each driving situation in order not to blind oncoming traffic or other road users with glare while giving the driver the best visibility at night. As lot of fatalities occur during dusk and night driving situations, this ADAS function is important in increasing traffic safety.

IMAGE3

In order to use such a system, first you must model the camera, which is usually mounted behind the windshield. Ideally you can import the model from a SPEOS simulation as described in the previous chapter. On each frame then the ambient light is hitting the object, being reflected, transmitted and/or scattered. The reflected light from this object is then propagated toward the camera sensor, which then induces a signal on the detector. The signal on the chip is then compiled as a picture of the environment. Different exposure times are used to generate a high dynamic range picture. Also, because the camera is also sensitive to near-infrared wavelengths, the picture might be quite different from what the driver is seeing. An algorithm then analyzes this picture. Detecting and labeling of objects may be done by Artificial Intelligence (AI) methods based on deep learning.

If an oncoming driver, pedestrian or other traffic user is detected, the eye position is calculated. This information is sent to the tail lamp which consists of a pixel light. The pixel light works like a projector, in which each zone in the environment is related to an emitting pixel. Embedded control software dims the pixels aimed toward the eyes of the other traffic members so they are not blinded by the glare. For some objects, like traffic signs, it is also necessary to control the light sent towards these objects. If using an efficient high beam, the light reflected from the traffic signs toward the diver’s eyes might be too intense, thus leading to a self-glaring effect. To prevent this, pixels related to the traffic signs will be dimmed.

For human vision, it is inefficient to put too much light in the foreground of the vehicle. The human eye adapts to the foreground, preventing the driver from seeing a pedestrian further down the road in the dark. Also, in this case it is important that each element of the scene gets the optimal amount of light for optimal driver vision.

Coming back to ROM models and multiphysics, we could imagine simulating the distortion of the camera lens as a function of temperature and saving this as a table into the ROM model. Then, during the system simulation, we just have to use the ambient temperature as an environmental parameter and simulate the camera’s response using the precalculated distortion from a look up table in real-time.

1.3 Standards for HAD Validation

The first standard for E/E (electric/electronic) systems that is relevant in this context is ISO 26262. ISO 26262 addresses safety risks that arise from malfunctions of the E/E system in the vehicle. This aims both at HW failures and at SW defects. The standard provides detailed recommendations of activities to perform for validation and verification on different levels. These levels include complete system as well as specific hardware (such as a camera) and the control or perception software involved.

ISO 26262 recommends use of testing and scenario simulation as means to achieve the verification and validation goals. For HAD, SPEOS and ANSYS VRX Driving Simulator cover traffic scenario simulation well. Testing is particularly relevant for SW-related activities where simulation does not apply. The ANSYS SCADE toolset supports a complete model-based workflow from model creation on architecture to code generation, model-based testing, target testing, and model-based test coverage measurement — all backed up by traceability capabilities to the requirements and documentation generation. All these tools are fully qualified according to ISO 26262, thus the code generated does not require review activities or back-to-back testing vs. the model it has been generated from. Also, the results of the verification tools mentioned do not need further verification against the inputs they were created from.

The other standard applicable here is PAS 21448 ("SOTIF" – Safety of the intended function). SOTIF does not deal with malfunctions within the system. Instead, it focuses on safety violations that can occur in a system free of malfunctions which relies on sensors that can produce potentially hazardous perceptions of the environment. While ISO 26262 naturally focuses on verification (does the system do things right?), SOTIF inherently aims at validation (does the system do the right thing?). This is particularly important for the perception system:

- Camera system/lidar/radar must work correctly (verified against specification)
- Perception SW must work correctly (verified against specification)

Validation is about finding corner cases where correct perception of the environment fails due to effects such as difficult lighting conditions, weather conditions, jitter/noise effects on the camera, insufficient training data for the AI perception software involved, etc. Validating all the combinations of these effects in the real world would result in billions of miles to be driven for testing. Even worse, in case of findings leading to modifications of the system, the mileage must be completely or partially repeated.

Here virtual testing comes into the picture. ANSYS SCADE Vision provides a framework to run these tests on recorded camera data. In addition, this visual data is augmented by SCADE Vision to greatly help in discovering corner cases in the perception system, thus contributing directly to increased perception maturity and robustness.

2 Outlook for future development of HAD functions

For HAD systems, it will be important to ensure that the autonomous systems can work in every imaginable weather condition. At the moment, we can see such systems driving in optimal weather, but during heavy rain or thick fog the driver will have to be put back in control. There is ongoing research on improving sensors *(REF6)*, for example, to enhance the spatial resolution of radar sensors as well as using different wavelength for the optical sensors from near-infrared (NIR, ~1,000 nm wavelength) toward short infrared (SWIR, ~1,500 nm wavelength). Another improvement can be achieved using real time map data and passive IR sensors which can detect the heat of any living object. These improvements will be necessary to enhance the usability of autonomous vehicles under safe conditions, which will be necessary for the acceptance and success of this new technology.

3 Images

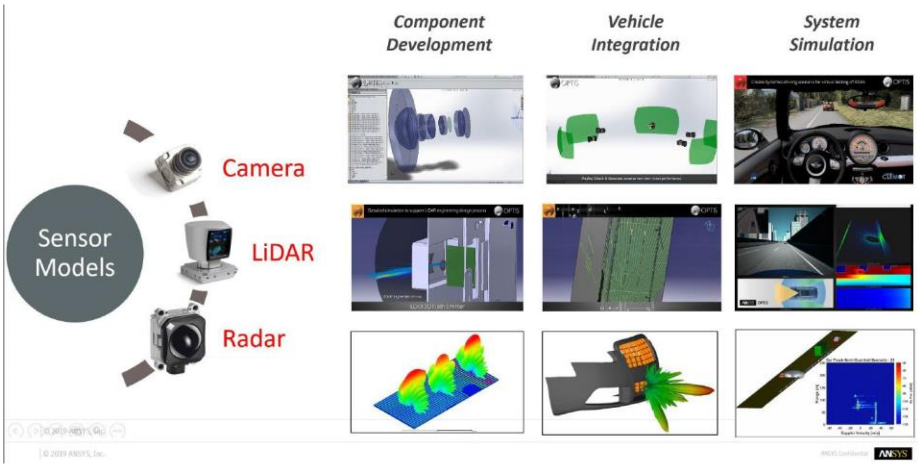

IMAGE1: Complete sensor simulation suite for AV

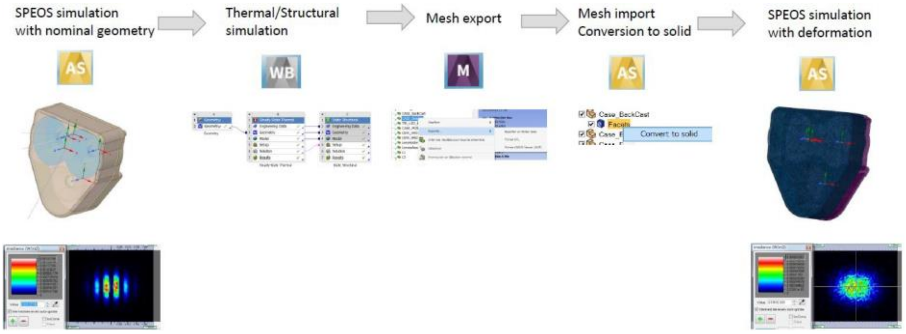

IMAGE2: Workflow of a multiphysics simulation

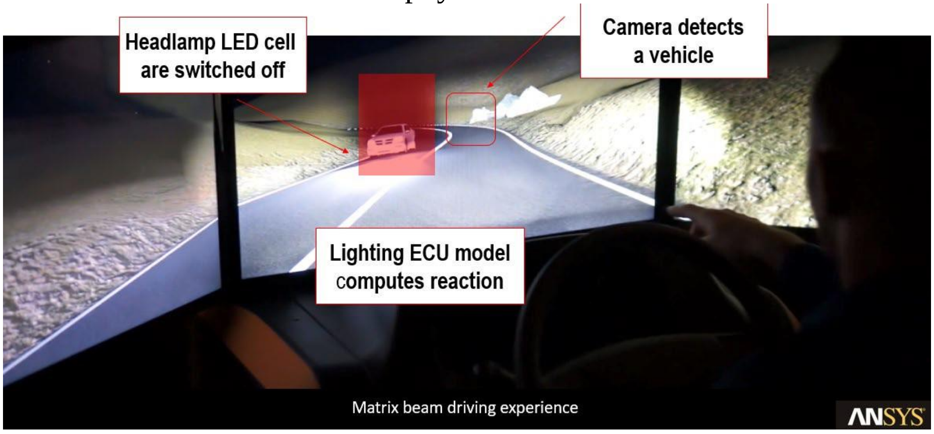

IMAGE 3: Headlamp assist ADAS function

4 References

Example below:

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