SCANeR studio / SE-Workbench-RF physical radar sensor

Florian FAUCHER[1,2], Jean LATGER[1], Aude MESNIL[1] and Christian RUIZ[1]

(1) OKTAL Synthetic Environment, 11 avenue du Lac - 31320 Vigoulet-Auzil - France, e-mail: {ffaucher, jlatger, amesnil, cruiz}@oktal-se.fr
(2) IRT SystemX, 2 Bd Thomas Gobert - 91120 Palaiseau - France, e-mail: florian.faucher@irt-systemx.fr

Abstract - *For the last few years, significant efforts have been made by software editors to introduce physical sensors models inside driving simulators. The aim of such models is to produce a scene rendering (raw data) or even observables (target list) with higher fidelity to reality. This fidelity is important for the automotive industry so as to cope with intrinsic flawed sensor information and to take these flaws into account as soon as possible in the design of the fusion and decision-making algorithms of the Autonomous Vehicle (AV). However, such sensors models often present two main limitations: the confidence in the Physics representativeness and the computation cost. This paper introduces the physical radar sensor interfaced to the simulator SCANeR studio and tries to answer how to overcome these challenges.*

Keywords: *Physical sensors, Ray tracing, Radar sensor, Synthetic environment*

Introduction

Autonomous vehicles are using sensors in order to get real-time perception of their environment. However, typical embedded low-cost sensors are sensitive to different types of disturbances depending on the physical domain involved. For instance, cameras are sensitive to weather disturbances while radar sensors are mostly sensitive to electrical conductor reflectors. Despite OEM efforts, improving their products (especially the detection processing algorithms), the accuracy of the delivered information remains a trade-off between design constraints, targeted accuracy and computational costs. Therefore, current Advanced Driver Assistance Systems (ADAS) and Autonomous Driving (AD) Functions must cope with noisy information or even false detections that are prone to lead to wrong decisions. As a result, modelling realistic sensor outputs in the simulation is becoming more and more important so as to consider these flawed outputs in the design and validation process of ADAS/AD functions fed by it. Literature usually mentions three different types of such sensor models, respectively from the least to the most complex and realistic: ideal, phenomenological and physical sensor models. Ideal and phenomenological models usually provide a list of relevant detected objects extracted from the semantic layer of the simulator. Nevertheless, the information provided by the phenomenological models is enriched with physical effects and/or technology-specific errors instead of conducting pure ground-truth extraction (Ahn, et al., 2020). These models are useful as they can easily plug an ADAS and require low computing resources. However, they are typically built thanks to laborious parametric studies that are conducted for a limited set of scenarios. Thus, the confidence in the observables provided by these models remains poor under more complex scenarios. The purpose of the physical sensor models is to overcome these limitations by providing raw input data for the sensor's perception algorithms. They are basically based on rasterization or ray tracing and a full overview of these technics is given by (Schlager, et al., 2020). The product presented in this paper is based on ray tracing technic but the purpose isn't to highlight the advantages of it. It rather aims at explaining the technological choices made by AV Simulation and Oktal-SE company for their common product in order to answer one of the difficulty that come with these kind of sensor models: how to reach real-time performances without losing confidence in the Physics representativeness ?

Product Solution

The product solution introduced in this paper is the outcome of an industrial partnership between AV Simulation and Oktal Synthetic Environment. Both companies are simulation software editors, the former designs and delivers a wide range of driving simulators and is the editor of SCANeR studio, a complete driving simulation software. The latter is specialized in sensors simulation and rendering. The collaboration between them leads to the physical sensors modules interfaced with SCANeR studio. Besides, both are "sister companies", with a common SOGECLAIR shareholder which strengthens and perpetuates the partnership.

SCANeR studio

SCANeR studio enables the user to configure and simulate complex traffic scenarios thanks to a wide 3D-object library and integrated tools. Among other things, it is possible to quickly design road infrastructures (like highways or urban areas for instance), and to define automotive scenarios. The SCANeR engine will then produce realistic trajectories and entity behaviors according to the scenario defined by the user. "Realistic", here, means that it takes into account various constraints imposed by vehicle behavior models or by instructions from an ADAS tested in closed loop. SCANeR also generates more complex and credible traffic scenarios by introducing random events. While designing a scenario, the user can configure sensors that will be held by a reference vehicle (ego vehicle). The outputs of such a sensor can further feed the ADAS aforementioned. More information can be found at (*AV Simulation, SCANeR studio* n.d.).

Figure 1: SCANeR studio main screen

SE-Workbench RF

SE-Workbench actually refers to the overall software suite of Oktal-SE (Douchin, Latger, and Cathala, 2017). Figure 2 shows that it offers a wide range of tools divided in three categories, enabling the user to model a synthetic environment, create sensor configurations and associated scenarios and set ray-tracing parameters to compute a physics based rendering in Electro-Optics (EO) or Radio-Frequency (RF) domain. A synthetic environment is a 3D geometric textured scene that also contains physical properties of the materials that composes each surface. The rendering tools are referring to the computation kernels of each physic domain. Several APIs enable the users to fully integrate these kernels within their own software environment. This is what has been actually done with SCANeR studio. Indeed, the physical radar sensor model of SCANeR uses SE-RAY-EM which is the ray tracing computation kernel in the radio-frequency domain. SE-RAY-EM performs computations thanks to 3D model extended by physical properties.

Physical radar sensor

Merging SE-RAY-EM with SCANeR mutually benefits from the advantages of each. SCANeR studio presents a large object catalog (vehicles, pedestrians, road infrastructures, traffic signs, etc.) when SE-RAY-EM is a high-fidelity and well-proven solution for RF rendering. However, these objects often do not fulfill the requirements of physic-based rendering, especially in automotive domain that is highly demanding in terms of geometry. Therefore, each object must

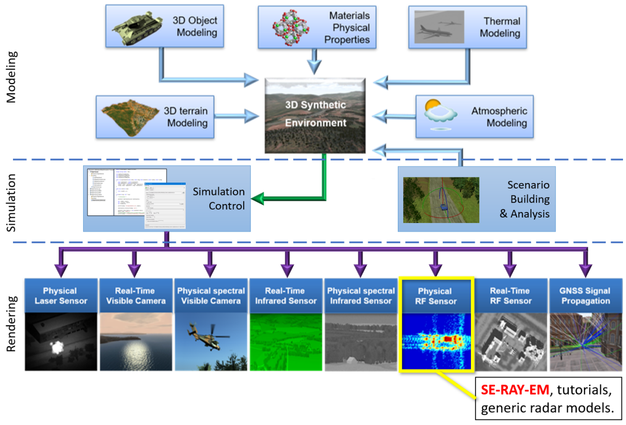

Figure 2: Global architecture of OKTAL-SE SE-Workbench

be converted into a comprehensive format for SE-RAY-EM before checking the geometry and adding physical properties on surfaces. This is an iterative process requiring manual operations and expertise. Figure 3 shows that the 3D scene render on the user screen matches the model used by SE-RAY-EM for the computation. At each timestep of the simulation, the interface reconstructs exactly the same environment and performs rendering computations.

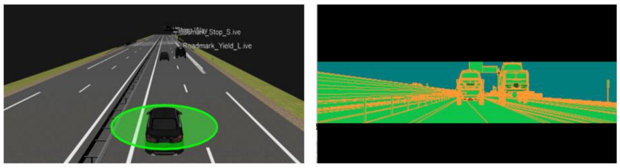

Figure 3: SCANeR view (left) and SE-RAY-EM view (right)

Without going into details, figure 4 shows the computation steps performed by the physical radar sensor module of SCANeR and that are common to the two levels that will be introduced in the following section. As soon as the synthetic environment is reconstructed, the computation kernel performs the ray tracing. From the emitted source up to the reception points, this step aims at find interactions between rays and the objects of the synthetic scene. The ray tracing enables to compute the EM fields in the scene that are composed of contributors. An EM contributor defines the EM Field diffused by a surface sample of the scene and mainly contains:

- the polarized complex EM field,
- the length of the ray path from the source to the receiver, considering the reflections and scatterings,
- the speed and acceleration of the path length due to moving entities of the scene along the path (source, receptor, and all reflecting or scattering entities),
- the direction of the emission,
- the location of the last scattering interaction.

Once all the contributors are gathered in the buffer, it is possible to filter only those that are in the radar field of view and that match the system boundaries. Then, they are sorted out in range and speed tables. This last step produces what it's called "raw data" later in this paper. More details about the SE-Workbench-RF and the rendering technic are given by (Douchin, Ruiz, et al., 2019; Latger and Cathala, 2015).

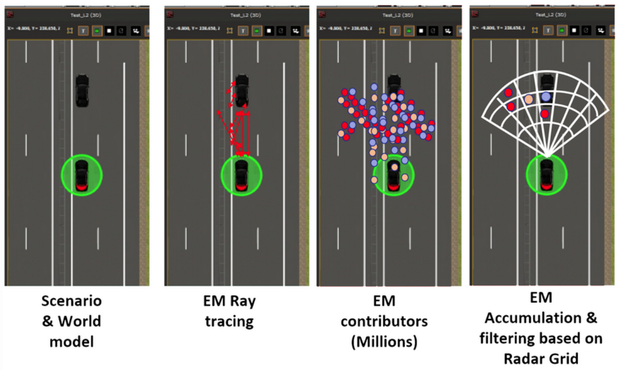

Figure 4: EM field computation steps

Methodology

As many other automotive simulators, SCANeR studio offers an ideal model and a physical sensor model. However, the physical sensor model of SCANeR studio is here divided in two sub-levels: a full-physics and an optimized level, that are both hereinafter described.

Ideal level - Level 1

The aim of this model is to feed an ADAS system with a full object list. This is an ideal representation of the real-world sensor. It does not simulate the signal propagation or any of the internal processing inside the sensor. It only uses the 3D World model and the Semantic layer. It performs simple geometrical detections to gather objects that are in the sensor's field of view and uses the semantic layer to extract the object list. The attribute information of the object list is called the ground truth. It is then possible to apply noise or errors to the attributes of the object list (distance, speed, etc.). This level does not rely on Oktal-SE product.

Full-physics level - Level 3

The purpose of the "full-physics level" or "physical-expert level" is to focus on high-fidelity rendering and Physics. Such a level requires high computational resources like the parameterization of the ray tracing, the radar grid resolution, the accuracy of the 3D model geometries, the texture segmentation with regard to physical material heterogeneity, etc. which are specifically tuned up for matching with the reality as much as possible. For this reason, it does not target real-time simulations in closed loop.

Validation reference

This level is actually the standard reference of the physics-based simulation so the raw outputs must be validated throughout a rigourous track tests and laboratory measurements campaign. The left side of the figure 5 shows that the previously mentioned processing blocs, integrated in SCANeR Studio, produce raw outputs that will then be used to tune up the so-called "optimized level" (introduced in the next section).

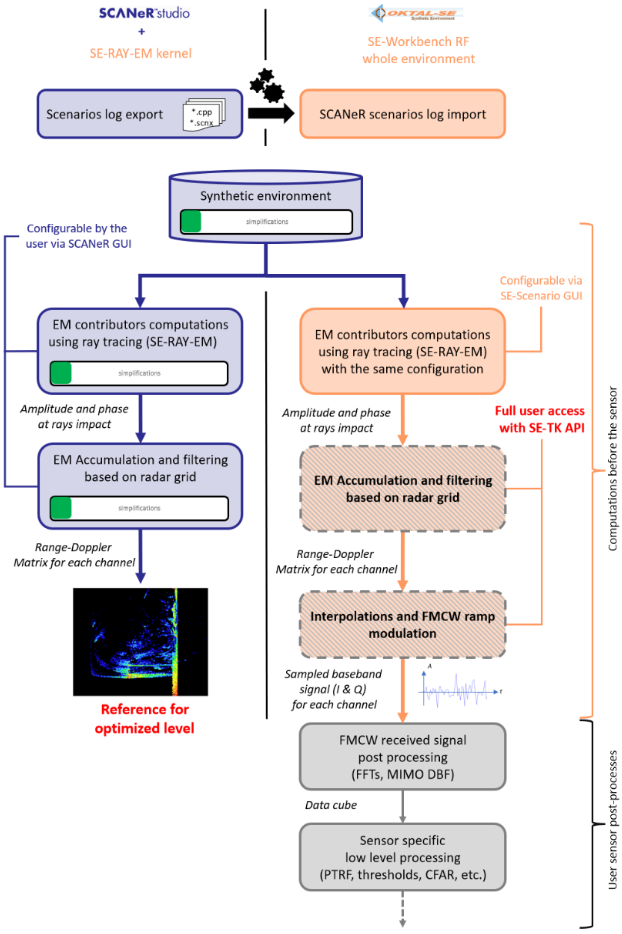

Figure 5: Physical expert level - processing steps

White-box mode and FMCW

In addition, the right side of the figure 5 shows that this physical-expert level provides sources that come with a dedicated Oktal-SE SE-TK API, which allows one to configure the quality of the electromagnetic raw data modelling and to tune-up the radar processing or even add or replace each radar processing steps with its own private models. Performing such an accurate level of customization requires the whole SE-Workbench-RF environment. Moreover, one can see that specific processing blocs are required for handling computation of the FMCW radar waveform propagation across the synthetic scene. These processing steps produce a baseband sampled signal (I & Q) at each reception point that is affected by disturbances such as loss, interferences, distortions, etc. Thus, the SE-TK API enables the user to process the raw data before the sensor itself. These steps are very resource demanding since each time sample requires a full range-doppler table to be further computed. However, performing full ray tracing rendering at the sample frequency would be inefficient so interpolated renders are made in between. Note that Multiple-Input Single-Output (MISO) and Multiple-Input Multiple-Output (MIMO) simulations are supported as well. Nevertheless, it requires to repeat each step of the aforementioned process flow for each channel and could result in gigabytes of exported data for only a few seconds of signal.

Interfaced mode

Finally, the top of the figure shows that the interface between SCANeR Studio and SE-WORKBENCH-RF is possible thanks to a scenario log file generator that is consistent with SE-Workbench. Thus, the user takes advantage of the power of SCANeR that provides highly realistic dynamic automotive scenarios and does not care for manipulating SCANeR directly. The user focuses on Physics representativeness and radar design or studies, using a library of SCANeR ready to use scenarios.

Typical use cases

Except for a validation purpose, physical-expert level rather addresses specialists of radar systems. More specifically, it can be used to conduct qualification and performance studies. For instance, it could be used to benchmark on-the-shelf sensor performances or tune up RF parameters of a real emulated radar system. Besides, this level may also be useful to car manufacturers willing to ensure how trustworthy the simulation is regarding their own requirements and needs.

Optimized level - Level 2

The purpose of the optimized level is to focus on performances without losing confidence regarding Physics representativeness. The same ray tracing technic is used for optimized and full-physics level since the computation kernel is the same. However, this level focuses on real-time execution thanks to any kind of simplifications that are applied on parametrization of the rendering, levels of detail on geometries and texture segmentation or generic sensor processing usages. Nevertheless, it is important to note that these simplifications can be assessed by comparison to the reference level meaning that the error can be quantified.

Real-time simulation

In this context, real-time execution often has two possible meanings. First, it can refer to Hardware-in-the-loop (HWIL) applications, with simulated raw data injected in the radar sensor (offline mode). This use requires a rendering frequency of about a few Hz. However, "real-time" sometimes refers to human in-the-loop applications that require rendering frequencies from 25Hz up to 60Hz. Today, reaching such performances remains a challenge and requires interpolated computations as well.

Generic sensor processing

Figure 6 shows that, unlike the physical-expert level, it is not possible to handle raw data modifications before the sensor. Moreover, there is no need to simulate as many impulse responses as required in real life. A single rendering is enough at the frequency required by the targeted real-time application. As already mentioned before, the EM contributors are then sorted out within range, Doppler and angle cells. Since we bypass the raw FM/CW signal processing here, the 3D raw matrix that could be obtained for each Emitter-Receiver antenna phase center couple represents what we call the Dirac simulated grid (only EM field, with no modulated signal).

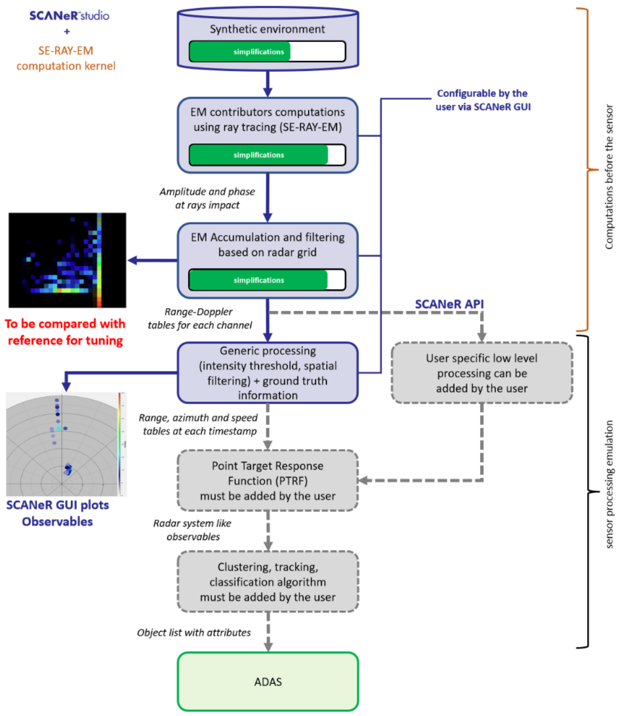

Figure 6: Optimized level - processing steps

Then, several generic processes are applied from these raw data such as intensity thresholds and spatial filtering enriched by ground truth information in order to produce range, azimuth, elevation and speed tables at each timestamp. It is important to note that the observables exported at this step doesn't stand for those one could really get from a real radar system. Indeed, the user still have to take into account the sensor Point Target Response (PTR) in order to get the same limitations and accuracies as in the real life. This includes the PTR in range, in Doppler and in angle. Of course, it depends on the system features of the radar sensor the user is intending to simulate and must be provided by him. Finally, clustering and tracking algorithms could follow up to the object list and attributes to feed an ADAS.

Integrated mode

Unlike the physical-expert level that is made for an interfaced use, the optimized level is fully integrated in SCANeR so the simulation is driven at SCANeR level only. The ray tracing and several parameters of the generic sensor processing are configurable thanks to a dedicated SCANeR Graphical User Interface (GUI). Besides, the SCANeR API enables the user to add his own missing processes blocs and/or to by-pass the generic processes in order to integrate his own private ones.

Typical use cases

This level essentially addresses car manufacturers since it provides observables that could feed a perception algorithm of a real sensor. Plus, by providing the missing processing blocs, the user would be able to feed an ADAS in a close Model-in-the-loop (MIL) simulation. Finally, the outputs provided by the generic sensor processing bloc could also be injected into a real radar system product for performing HWIL or even Human-in-the-loop simulations.

The tuning phase of both levels

The tuning phase has two main goals. First, it aims at finding the minimal parameter set that still offers the same high-fidelity results for the reference level. Second, for a given configuration, it aims at finding the parameter set that is a trade-off between representativeness and computational performances required for the targeted application (MIL or HWIL). Figure 7 shows that simplifications are made by the user from a reference point so it is possible to assess and quantify the accuracy loss along this phase. The simplifications could be done on sensor processing, ray tracing parameters (grid dimension, anti-aliasing, optical paths, geometrical accuracy, etc.) and scene accuracy.

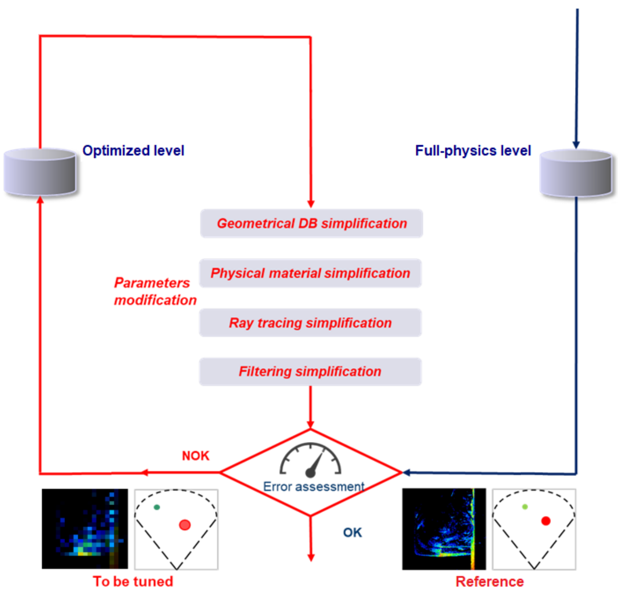

Figure 7: SE-Workbench

Results and Discussion

This section gives a brief overview of the integration progress status, the validation campaign of the reference level as well as the performances reached so far.

Software integration

The integration of SE-RAY-EM and the pipe connection for both levels have been checked through campaign of unit and functional tests and are fully operational. However, improvements will be added in the future. For instance, the coherence of the entities animations: some objects such as the wheels of the vehicles in SCANeR and the models handled by SE-RAY-EM are not well synchronized. Such close coupling between both tools would be all the more relevant for pedestrians animations.

Validation campaign

Linked with the validation of the full-physics level, AV Simulation and Oktal Synthetic Environment jointly contribute to the project named *Simulation for the Safety of Systems in Autonomous Vehicles (3SA)* n.d. held by the French institute SystemX. Track tests and lab measurements are currently conducted by SystemX to provide real driving data and characterization data of a real automotive radar sensor, including antenna pattern diagrams and Radar Cross Section (RCS) measurements.

Optimized level performances

Regarding the optimized level, the performances highly depend on material configuration of the computer running the simulation. It also depends on the complexity of the scenario, the complexity of the geometries involved, the parametrization of the ray tracing, and potentially also on other modules running by SCANeR. However, a rendering frequency up to 30/40 Hz has already been reached on a hardware setup including a simple 1080 TI GPU.

Conclusion

This paper intends to clarify the respective roles and advantages of SCANeR studio and SE-Workbench within a radar automotive simulation context. SCANeR focuses on automotive when SE-Workbench focuses on Physics propagation and sensors. The win-win association of these tools induces a key differentiator on the automotive simulation market that is unique. The physical radar sensor of SCANeR studio / SE-Workbench presented here on the RADAR application comes with a sub-level decomposition: a full-physics level and an optimized level. Since physics-based rendering is highly demanding in terms of computations resources, we argue that it would be more relevant to focus either on high fidelity or performances separately. The full-physics level is not a real-time mode because it aims at validating the synthetic environment, i.e. geometry and material properties specific to the automotive domain. On the other hand, the optimized level is dedicated to real-time simulations and aims at feeding an ADAS in a close loop simulation. However, this level also remains trustworthy in terms of physical representativeness because it is derived from the full-physics level which is a reference. Moreover, the user fully controls and decides which simplifications to apply in order to get the performances targeted. Besides, this RADAR approach of simulation using, the SCANeR and SE-Workbench duality can be applied to other sensors such as Visible Color cameras, visible short-wavelength infrared (VIS-SWIR) or long-wavelength infrared (VIS-LWIR) cameras, LiDAR, infrared cameras and also to GNSS sensors, which is on the road in between AV Simulation and OKTAL-SE sisters companies of SOGECLAIR group.

References

Ahn, N., Hofer, A., Herrmann, M., and Donn, C., 2020. Real-time Simulation of Physical Multi-sensor Setups. *ATZelectronics worldwide*.

AV Simulation, SCANeR studio n.d. `https://www.avsimulation.com/scaner-studio/`.

Douchin, N., Latger, J., and Cathala, T., 2017. *Multi Sensors simulation for missile applications*. Available at https://www.oktal-se.fr/download/18/company/4196/multi-sensors-simulation-for-missile-applications.pdf.

Douchin, N., Ruiz, C., Israel, J., and Mametsa, H.-J., 2019. SE-Workbench-RF: Performant and High-Fidelity Raw Data Generation for Various Radar Applications. In: *The International Radar Symposium IRS 2019*. Available at https://www.oktal-se.fr/download/15/radio-frequency-radar/4186/se-workbench-rf-performant-and-high-fidelity-raw-data-generation-for-various-radar-applications.pdf.

Latger, J. and Cathala, T., 2015. *Millimeter waves sensor modeling and simulation*. Available at https://www.oktal-se.fr/download/15/radio-frequency-radar/4168/millimeter-waves-sensor-modeling-and-simulation.pdf.

Schlager, B., Muckenhuber, S., Schmidt, S., Holzer, H., Rott, R., Maier, F., Saad, K., Kirchengast, M., Stettinger, G., Watzenig, D., and Ruebsam, J., Oct. 2020. State-of-the-Art Sensor Models for Virtual Testing of Advanced Driver Assistance Systems/Autonomous Driving Functions. *SAE International Journal of Connected and Automated Vehicles*, 3, pp. 233–261.

Simulation for the Safety of Systems in Autonomous Vehicles (3SA) n.d. https://www.irt-systemx.fr/en/projets/3sa/. Launched in 2019 for a period of 4 years, the project 3SA (Simulation for the Safety of Systems in Autonomous Vehicles), which is an extension of the SVA project, aims to go further in the use of digital simulation for demonstrate the safety of the particular autonomous vehicle.