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Virtual environment modeling for accurate Radar sensor simulation

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Abstract – Safety of Autonomous systems is a big challenge faced by the current automotive industry, especially with the latest technological advancements and the recent emergence of level 4 Autonomous vehicles. More and more standards are being published as a means to ensure safety of the public as these vehicles roll out for the public. Among the challenges faced by the industry is the safety of autonomous systems and how they interact with the real world. The main challenges of the autonomous systems are the perception systems, with more complex technology being deployed every year. Simulations as a means of validations is not new, however as the technology becomes much more complex, simulations must be accurate enough to represent real life scenarios. One of the tasks of the project is to ensure the accuracy of radar as a means of perception. Through simulation, time to market is significantly reduced, and testing can be done anywhere. However, all factors of the simulation workflow must be considered to ensure that the results obtained from validation via simulation is valid and can replace real life testing. Physically realistic simulations of radar consist of two main factors, from a hardware point of view modelling the radar in numerical format is imperative to having an artificial block in the simulate environment, and to the topography and contents of the environment that interact well and correctly with the radar model. This paper aims at discussing the requirements of virtual environment modelling and how accurate they should be to reproduce accurately a Radar sensor response.

Keywords: Radar, Safety, Realism, Simulation, AD/ADAS

Introduction

The development of autonomous transport technologies and road networks requires the implementation of reliable tool. It is with this objective in mind that IRT SystemX and its partners have started work on the SVA project (2015). With regard to the modelling of ADAS sensors on board an autonomous vehicle, work is being carried out on the camera, LiDAR, navigation and especially radar, which will be the focus of this paper.

Initial developments used ideal or geometric sensor models constructed from data in technical data sheets provided by equipment manufacturers. The limitation of these models was that they did not consider the physics of the waves, the geometry, materials and behaviour of the targets (Abadpour, S. and a. (2021)), or the influence of environmental elements (infrastructure elements, weather) that could interfere with detection (Winter, 2021). In order to arrive at a consolidated virtual sensor model, the physically based model, constructed from empirical data relating to the characterisation of the sensor in question (Palmier, 2022) and the construction of the vehicle's synthetic environment, is identified. To

ensure the reliability of the simulation of an autonomous vehicle in its environment, it is important to validate the response of the sensors by considering external disturbances. This is the objective of the CVH project team, which includes IRT SystemX, AVSimulation, IMT Atlantique, OKTAL-SE and the Renault Group.

This paper focuses on one part of the methodology. By distinguishing the work carried out in both real experiments and simulation, the focus is on the development of simulation scenarios with initial results that allow conclusions to be drawn.

Methodology

In order to have a pertinent and realistic simulation environment, the workflow was set up to take into account all the measurements necessary, as well as all physical phenomenas that is associated with the environment of the autonomous carrier vehicle (also referred to as ego).

This allows for the reproduction of real scenarios into the simulation environment. Fig. 1 summarizes this part of the methodology according to these two channels.

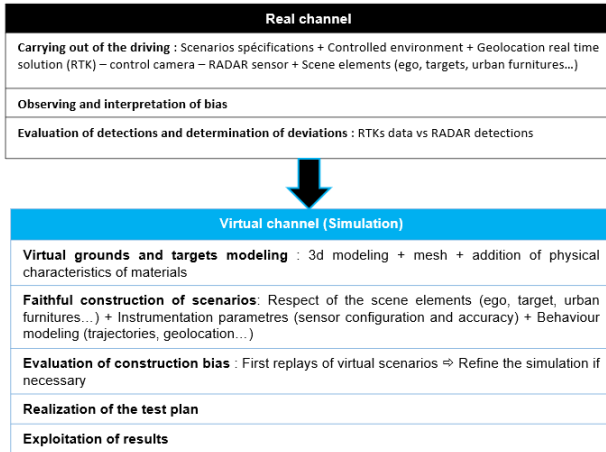


Figure 1 Methodology protocol

Real data collect campaign

During the previous project 3SA (Simulation for the Safety of Autonomous Systems) led by IRT SystemX, a whole campaign of real data acquisition was carried out with the goal of having a complete methodology of characterizing a Radar sensor in simulation. This work has been done in two parts: a first acquisition campaign was done in collaboration with IMT Atlantique for characterizing the radar and analysing the Radar Cross Section of several targets (Palmier, V. and al., 2022), a second acquisition campaign, subject of this paper, has been done with UTAC in order to have driving use case with a variety of scenarios and environments.

Presentation of actors and tools

Ego

The term ego refers to the vehicle carrying the radar, also carrying an RTK system (real time kinematic system) for the reconstruction of simulated scenarios), at the centre of gravity of the vehicle.



Figure 2 Ego vehicle with the RADAR in front of the logo

Targets

Targets are comprised of other vehicles and a motorbike which carry an RTK system for the vehicles and a RT-range system for the motorbike. All the targets have been measured for their Radar Cross Section in laboratory, via a reference bench and via radar, to achieve the most faithful modeling possible.

Radar

Radars (Radio Detection and Ranging) are one of the main sensor technologies used for AD/ADAS due to their resilience in front of several kind of weather perturbations and their accurate evaluation of relative speed of targets.

Radars rely on electromagnetic waves emission and reception by comparing time of flight and frequency variation to evaluate distance along with speed and angle of the target that are measured.

We're utilizing a 76-81GHz radar supplied by NXP. The central frequency is parameterized at 78 GHz, configured with a 200MHz bandwidth which means it has a range resolution of about 75.3 centimeters and a velocity resolution of about 0.3945 m/s.

This radar is equipped with 3 transmission antennas and 4 receiving antennas (see Fig. 3). The azimuthal field of view of the transmission antenna's array is equal to 60° and the elevation is equal to 11°. For the receiving antenna's array, the azimuthal field of view is equal to 90°.

The receiver power depends of the detected signal, it is obtained by the telecommunications equation:

$$Prx (W) = \frac{Plx * \sigma * Gtx * Grx * \lambda^2}{R^4 * (4\pi)^3}$$

The transmission gain (G_{tx}) is equal to 21dB and the receiver gain (G_{rx}) is equal to 18dB. The transmitted power (P_{tx}) is equal to 11 dB. R is the range between the radar and the target in meter, λ is the wavelength ($38.10^{-3}m$ for a 79 GHZ frequency) and σ , in square meter is the radar cross section of the target.

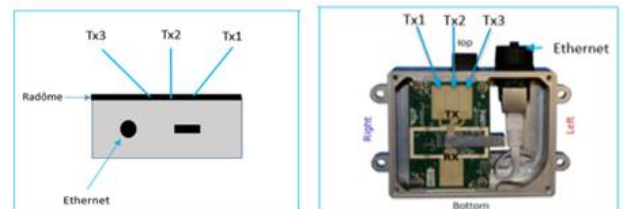


Figure 3 Location of the radar antenna

The radar capacity detection is $256 * 128 = 32\ 768$ range-doppler detection points, with the range resolution and the speed resolution that implies: a maximum range:

$$R_{max} = 256 * \Delta r = 192.7\ m$$

a maximum relative speed

$$V_{max} = 128 * \Delta v = 50.5\ m/s$$

In regard to the radar processing, 3 fast Fourier transforms are employed to obtain the range, the Doppler, and the angle of the detection points. Subsequently, CFAR (constant false alarm rate) detection is initiated, and the process culminates at the target map.

The radar processing does not include the clustering of points belonging to the same target, nor does it include tracking, which would allow for target tracking after the clustering stage.

Control camera

The control camera is carried by the “ego” allows for a secondary means of confirmation of the events that take place on the track alongside the RTK data recorded previously.

Experimental protocol

Environment

The real-world experiments will enable us to acquire so-called real-world data on the ground during driving on test tracks. It takes into 9 use cases identified in advance. All of them have been described with actors, speeds, minimum and maximum distances between actors. All our tests were carried out at the TEQMO (UTAC CERAM) (Fig. 4). They also define the behaviour of actors on the road. The geometry, and the materials of the objects in the surrounding area have importance on the outputs of such sensors, and are taken into account for their modulization for simulation.

The project's goal to accurately recreate radar responses in a virtual setting necessitates the placement of certain infrastructure components on the road to study electromagnetic phenomena.

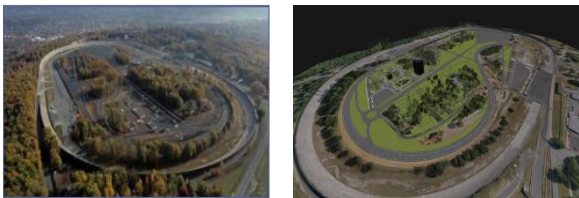


Figure 4 TEQMO road, UTAC CERAM and its virtual modeling

All driving use-case have been repeated 2 or 3 times with 2 configurations for the radar.

Fig. 5 illustrated a study example of a real driving use-case with ego traveling on the right lane with a Zoe located straight in front of it at a distance of 27.75 meters (based on RTK data) and with a speed almost equal to that of the ego (doppler=0.11m/s, RTK data).

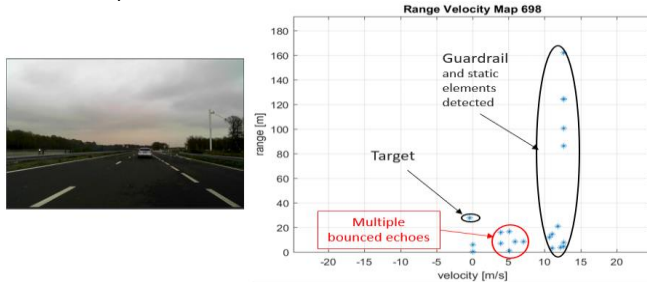


Figure 5 Range Doppler map radar detection for one target duration of 34 seconds with a total of 136 radar acquisitions

First results of the outputs radar data show that the target is detected by the radar with a distance equal to 27.75m and a doppler equal 0.3975m/s (= velocity resolution). On the right of Fig. 5, the detections of the guardrail and of static elements are visible, and the echoes bounce phenomenon is detected by the radar. This type of disruptive phenomenon is part of the scope of the methodology by first identifying them and then modelling them mathematically.

Radar data in simulation

The aims of such simulation tools are the representativity in term of accuracy, format, noise, and performance of the sensors that are being characterized. For each kind of sensor, the state of the art is already well developed (Schlager, Schmidts, Maier, & Saad, 2020) and several technics (especially based on ray casting or ray tracing methods) that reproduce these kinds of models for Radar sensors. Nevertheless, simulation models do not only rely on sensor model but also on the modelling of the environment.

SCANer Studio

SCANer Studio is a simulation software developed by AVSimulation aiming at modelling several aspects of automated driving going from vehicle dynamics, environment, human factors, headlights to sensor models, motion, or algorithms. The software also includes the physical sensor model of SE-WORKBENCH, enabling a high-fidelity modelling of diverse accurate situations, considering the physical phenomena's that can be a result of the environment.

Simulation process

Sensor characterizing

A first step of modelling implies the parametrization of the sensor. In order to have a high-fidelity model, special attention is given to the precise position of the sensor, its field of views and orientation. The sensor should also be characterized in terms of antenna diagrams, power of the radar, apertures and gain (Palmier, and al., 2022).

For the first step of the built of simulation scenarios, the antenna patterns have not been considered and they assimilated to a gaussian antenna in transmission and a generical antenna in reception.

This choice can be explained by the fact that the construction of the virtual environment is realized with different parts of methodology workflow built simultaneously. That's the case of the modeling of targets or of the modeling of the tunnel which have been made during the modeling of the virtual radar sensor.

The resolutions in terms of velocity and range are not the same as those of real radar either.

About the signal processing, the processing of simulation is under construction to match with the real radar processing that means, at this stage of development, the filtering in particular is not the same in simulation as that carried out by the real radar software.

Modelling constraints

The goal of physically modelling sensor radar response needs a correct representation of objects and environments around the sensor. This representation must be representative in terms of geometry and in terms of materials. Through tools from OKTAL-SE, OBJ files can be converted into physically classified object (named SDM files) that represent the associated objects (Fig 6).

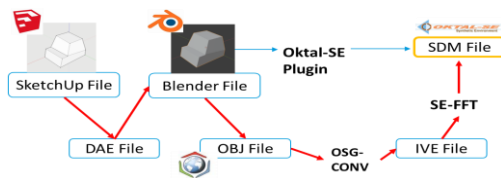


Figure 6: Applied workflow of 3D modeling

Terrain modelling

SCANer Studio already provides well modelled terrains with geo-localized data, buildings footprints, and road logical content providing accurate positioned data. On top of such models, there is a need of providing physically classified data, which means accurate geometry and materials description through the tools of SE-WORKBENCH.

Trajectories and behaviour modelling

Acquisitions of driving data done at UTAC (Fig. 4) provide localization data acquired from RTK measurements for each target allows the reconstruction of accurate scenarios and positioning of each vehicle.

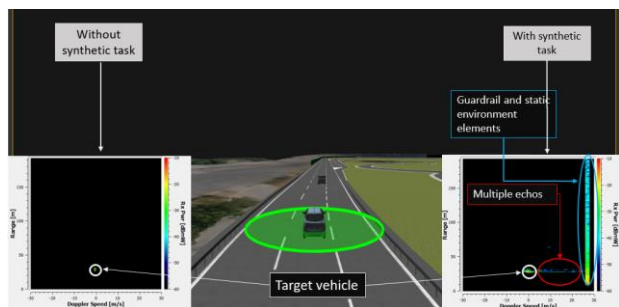


Figure 7 Simulated data from the real scenario of Fig 5

On the basis of this use case example (Fig 5), Fig. 7 highlights the reliability of the method for constructing virtual behaviour based on reality on the ground. With an average distance difference equals of 0,21m calculated from 34,000 moments over the 34 seconds of driving and the observation of several multiple bounced echoes (Fig. 7 right), the

differences in distance show the almost perfect similarity between simulation and reality.

To highlight the interest of taking good account of the geometry during the modeling step of the methodology (Holder, 2019), specifically for physical-based calculation in the field of radio frequencies, this study presents the results obtained with three of virtual tunnel visualisation (Fig. 8). There is no target in this scenario. The goal is to observe the signal rendering of the tunnel without target so without multi-bounces between target and tunnel.

The range-doppler maps are obtained at the same moment of driving. It can be seen that the improved tunnel geometry provides a better rendering of the multi-bounce effect on the tunnel walls. On the other hand, the range-doppler map remains unchanged when the tunnel with reinforcement is changed to one with lining and corrugated sheeting.

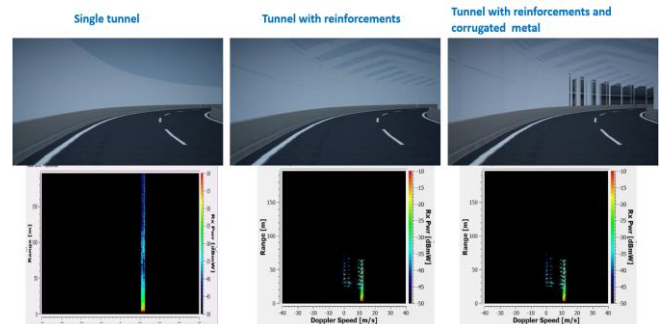


Figure 8 Simulation range doppler rendering at the same moment of the driving with 3 types of modeling of tunnel

This shows that geometry plays an important role in the realism of the simulation, while noting that at a certain level of modeling, the calculation will take longer without necessarily providing more information.

It cannot be denied that validating the radar model by comparing it to the real radar is a crucial part of developing a comprehensive radar model (Kannanthara, 2023), (Magosi Z. a., 2023). Also, it is interesting to note that as the fidelity of the tunnel geometry increases, the simulation follows the behaviour of the actual radar response.

Conclusion

This paper puts forth a workflow for the creation of a dependable synthetic environment, with the aim of fostering wider acceptance of simulation as a means of validating radar systems. While this paper does not focus on target detection, it does illustrate the necessity for precise modelling of the diverse elements within the scene, particularly their trajectories and geometry. The use case illustrated in Fig. 7 provides an apt demonstration of this necessity. As in the real case depicted in Fig. 5, the

phenomenon of multiple echoes emerges when the environment is subjected to a physical characterisation and incorporated into the physics-based calculation. As illustrated by the case of the tunnel (Fig. 8), the necessity of precise geometric modelling for simulation is evident. Nevertheless, it is essential to ascertain the degree of precision required for the model geometry in order to guarantee an efficient and expeditious workflow.

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