A Simulator for Multi-User Automotive Radar Scenarios

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***Abstract*—Radar is an essential element of state of the art advanced driver assistance systems. In the foreseeable future, radar will be an indispensable sensor for the use in affordable, automated driven cars. Simulation tools are the key for an efficient development process and hence will lower the price of sophisticated driver assistance systems. Therefore, the development of adequate simulators is important for suppliers, car makers, and final consumers. This paper introduces the concept of such a simulator for multi-user automotive radar scenarios and presents selected simulation results for a use case of radar interference.**

***Keywords*—Automotive radar, system simulation, radar interference**

I. Introduction

The simulation of a complete car including its subsystems is an objective of automobile manufactures and its supplier industry. Commercial software tools like *CarMaker* [1] already support the development of driver assistance systems and are continuously further developed. However, the use of sophisticated wave propagation (WP) simulations for the prediction of the radio- or radar channel is not yet common in system simulations, which are used in the car industry. Within the frame of research projects, the car industry supports the development of such system simulations [2], which also cover the simulation of the WP for radar operation including targets [3]. Such system simulations are especially beneficial, if interference between automotive radars is investigated. The number of radars on the street can be increased arbitrarily in simulations, and therefore meaningful results can be derived [4], [5]. This paper presents a simulator, which can be used to test radar systems virtually. Section II introduces the overall concept. Section III describes the generation of scenarios, which can be used for a system simulation. Section IV briefly introduces the used WP-tool and the method how the RCS is modeled in the radar simulations. Section V defines an exemplary radar for a virtual test in a multi-user radar scenario. Finally, Section VI concludes this paper.

II. Concept of the System Simulator

A virtual test drive is made possible by the modular system simulation shown in Fig. 1. The overall simulation run is controlled by MATLAB. The latter provides input data for the individual function blocks, triggers them, and catches the resulting output data. A system simulation starts a manual or automatic generation of scenarios.

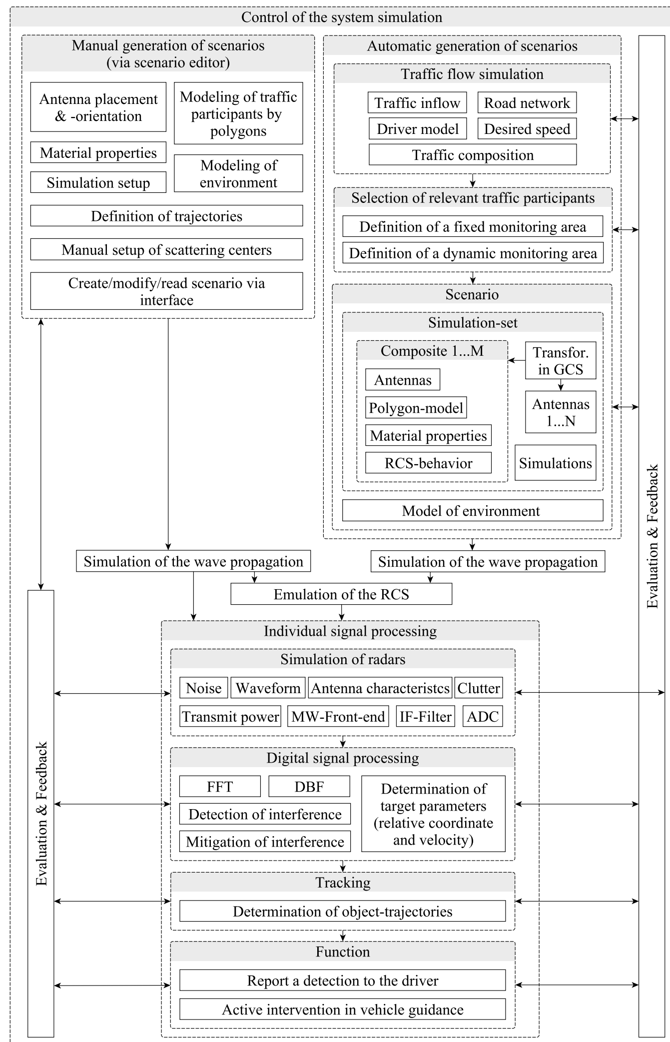

Fig. 1: Concept of the system simulator for automotive radars.

III. Generation of Scenarios

A. Manual Generation of Scenarios

A manual generation allows the modeling of a scenario in every detail, including the trajectories of the vehicles. It is best suited for seldom or risky driving situations, like near misses or

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accidents. It is also adequate for special test scenarios defined by the Euro NCAP [6].
The tradeoff for flexibility is the obligation to model every detail yourself. To make this as comfortable as possible, special software tools are necessary. These editing tools must support the polygon based modeling of objects, the definition of the latters' material parameters, the placement of sensors/antennas, the definition of arbitrary trajectories, and a preview of the generated scenario as a function of time. If the editing tool is further controllable via an interface, single snapshots can be exported. This permits the inclusion of the driver's or subsystem's reaction on events. An example for a system simulation based on a manual scenario generation is shown in Fig. 2. It is a special case of the overall concept shown in Fig. 1.

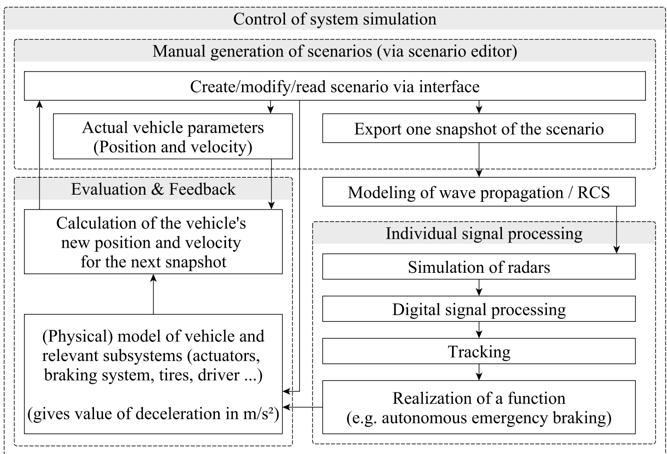

Fig. 2: A manual generation of a scenario with a feedback in order to make a reaction of a driver or subsystem possible.

B. Automatic Generation of Scenarios

Alternatively, the microscopic traffic flow can be modeled by software tools like VISSIM [7] or SUMO [8]. For the simulator presented here, VISSIM was chosen for modeling the traffic behavior. It allows the generation of complex traffic scenarios and provides information about a vehicle with respect to global position, orientation, velocity, and the sort of vehicle (car, van, lorry, motorbike, pedestrian) as a function of time. Once a scenario is set up, traffic flow data for several hours of driving can be generated and exported. It is beneficial to reduce the traffic flow data to the necessary information before handing it over to the wave-propagation simulation. This task is accomplished by two kinds of monitoring areas, which preselect vehicles of interest. The fixed monitoring area is suitable, if many independent snapshots of a scenario should be analyzed (see Fig. 3), for example to calculate the interference potential between automotive radars and to derive statistical results, as demonstrated in [5].
If the radar system as a whole should be simulated, the dynamic monitoring area is the preferred choice (see Fig. 4). The monitoring area is updated with the movement of the victim car. The car is initially selected from a definable starting-area. As soon as the car leaves the area marked with termination condition, a new car is selected from the starting-area. This procedure allows the simulation of many driving maneuvers of the same kind in a loop.

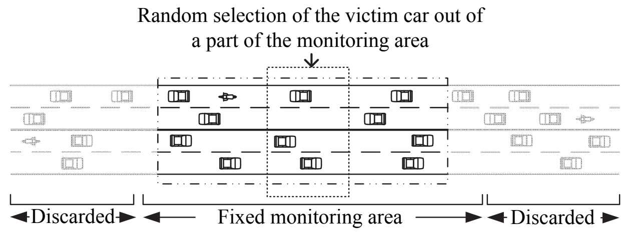

Fig. 3: Principle of a fixed monitoring area.

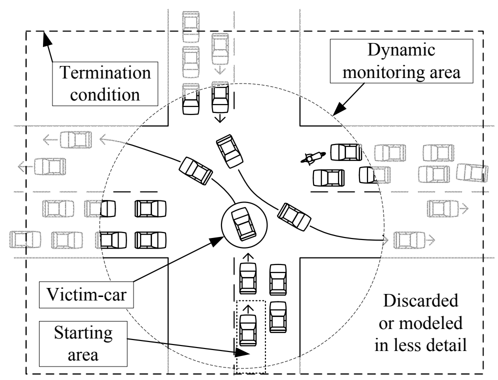

Fig. 4: Principle of a dynamic monitoring area.

The filtered traffic flow data is used to create a scenario, which is later used to set up the simulation with an user-definable WP-tool. The scenario with its most essential functionalities is shown in Fig. 1. It consists of two units. In the simulation-set, M objects from the traffic flow simulation are represented by composite-objects, which hold information about the antenna placement, the (polygon-)model and material properties. Further the emulation of a defined RCS-backscattering behavior can be activated for a composite-object, if desired. This must happen before the WP simulation, because the modeling of RCS is based on the processing of scattering centers, which are realized by antennas. Every composite-object is transformed according to the trajectories provided by the traffic flow simulation in the global coordinate system (GCS). It is useful to allow additional N antennas in the scenario to consider for example speed-meters or fixed links. Every simulation-set further contains simulation-objects, which summarize all necessary details for the following WP simulation. Two different kinds of simulations exist, one for communication links, and one for radar operation. The difference is explained in Section IV. The second unit of a scenario is the environment, which can be defined including additional models. Ideally, the environment can be extracted from the traffic flow modeling tool.

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IV. Wave Propagation Simulation

Here, the current version of the verified ray-tracing model (RTM) from the Institut für Hochfrequenztechnik und Elektronik is used [9]. The RTM was used in a series of academic works concerned with communication or radar [4], [10]. The RTM uses an efficient geometric optics implementation, includes diffraction effects based on the uniform geometrical theory of diffraction, and a volume based scattering model for vegetation [11]. Modified Fresnel reflection coefficients are used for modeling the reflection at rough surfaces [11]. Configurable point-scatterers exist to model a certain backscattering behavior. The ray-tracing is done full-polarimetrically in 3D and allows several interactions within one propagation path, except for the configurable point-scatterers which are limited to one interaction. The results from the WP simulation are complex transfer factors for every propagation path, containing information about the amplitude, phase, delay, Doppler-frequency shift, and outgoing and incoming angles for both involved transmitting(TX)- and receiving(RX)-antennas for one frequency. The WP simulation can be run for several frequencies if a broadband characterization of the channel is needed.

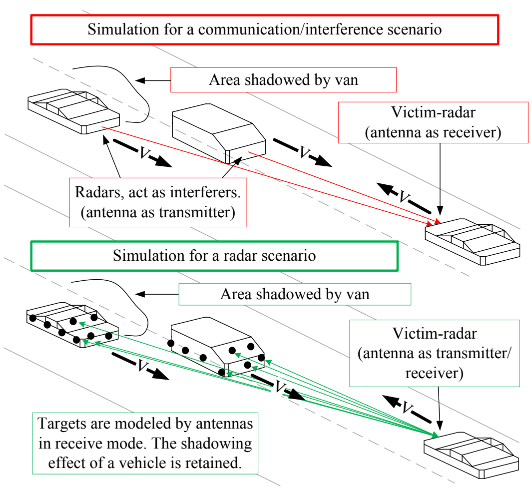

Fig. 5: Simulation of the WP for an interfered radar in two steps. The scattering centers use monostatic RCS data.

Originally, the RTM was developed for communications. When investigating interference between automotive radars, the model is already well suited, because such scenarios correspond to a classical case of a communication link.
If the WP should be simulated for a radar, the pre-defined RCS-behavior of a composite-object is emulated. This is done by introducing free positionable replacement antennas (FEA) for composite-objects (see Fig. 5). With these FEA, arbitrary scattering centers can be realized or the composite-object can be substituted completely by simulated or measured RCS characteristics [12], while its shadowing effects are retained. In comparison to the modeling by the former point-scatterers, the backscattering now includes multipath propagation. The results from the WP simulation, including the post-processing of the RCS, is stored in a user-defined format, as input for the signal processing.

V. Signal Processing and Selected Results

As a practical example, the simulation of a generic forward looking FMCW-radar with Digital Beam-Forming (DBF) capabilities at 24 GHz, which is interfered by other radars, is briefly described and demonstrated. A roundabout is chosen as a low speed traffic scenario (see Fig. 6). All cars are equipped with 3 mid-range radars, one forward-looking radar and two backward-looking radars for blindspot detection and lane change assistance. For the WP simulation, all radars are modelled by one antenna to save computation time. The number of radar antennas for the victim is later virtually increased to 8 by using the method described in [13]. All vehicles are declared as radar targets and therefore a realistic backscattering and shadowing behavior is considered. The WP simulation is done for a carrier frequency of 24.125 GHz and provides the transfer factors between all TX- and RX-antennas. To simplify the example, an idealized clustering approach was used, which accumulates multiple RCS scattering points of a target to the origin of its local coordinate system and updates the resulting transfer factors accordingly. The transfer factors are based on a simulation with omni-directional antennas, which allows the post-processing of real antenna patterns, because the incoming and outgoing angles of the propagation paths are known. The observed victim-radar is a forward-looking radar and uses an FMCW-waveform. It consists of three sections: one up-ramp and one down-ramp with 200 MHz bandwidth each, and a CW-signal. Every ramp has a duration of 6 ms. The maximum desired range of the radar is set to 50 m. All other radars are interferers and their waveforms are uncorrelated with the waveform of the victim-radar (different frequency slopes of the ramps). The undisturbed and disturbed radar receive signals are modeled in the baseband including amplification, mixing, filtering and dynamic compression. After quantization, the time domain signal can be checked for interference, which is mitigated, if desired and possible. In this demonstration, no mitigation is performed. A windowing follows prior to the fast Fourier transform. The DBF-processing is done as described in [14], followed by a tracking procedure based on a linear Kalman filter with additional plausibility checks to handle a multi-target environment as it is considered here. The simulation results show the valid tracks for the undisturbed

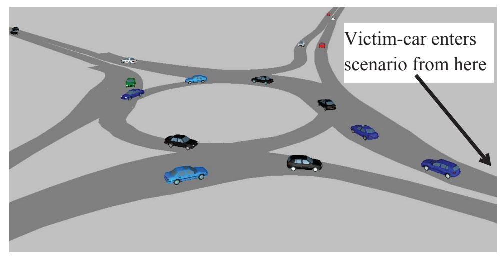

Fig. 6: A roundabout as a typical urban traffic environment.

radar (Fig. 7) and for the disturbed radar (Fig. 8). The physical driving situation is exactly the same for both cases. The duration of the scenario is 1.5 s to avoid the overlapping of the tracks in the figures. If the victim-radar is undisturbed, the tracks of the three cars driving ahead of it exist without gaps. If the radars from the other cars are in operation, interference occurs and the tracks of car A and C are affected; the last position of A and about 60% of the positions of car C are lost. Further details are described in the captions of Figs. 7 and 8.

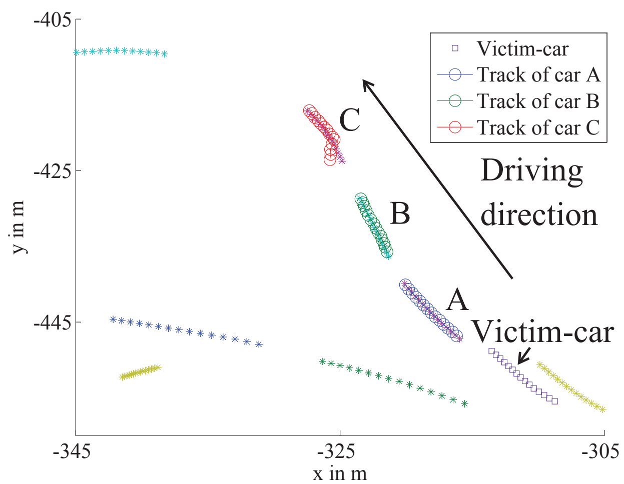

Fig. 7: This figure shows the valid tracks of objects, without interference. The known object positions from the traffic flow simulation are marked by stars. The three cars in front of the victim car are visible and the tracks can be regarded as a reference.

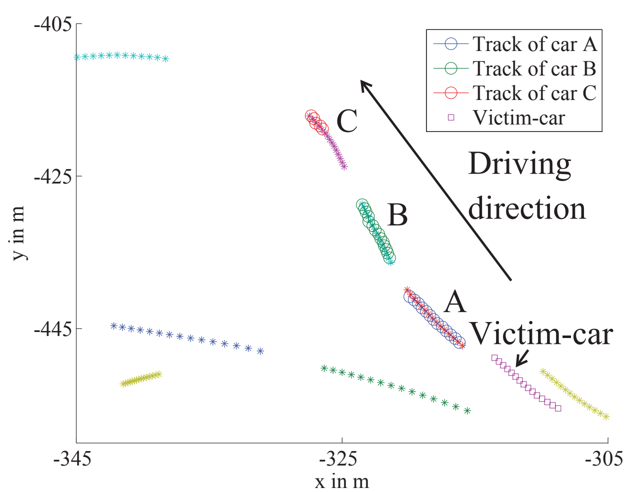

Fig. 8: Here the valid tracks of objects are shown, with interference between radars. The victim-radar loses several detections, but can still create the tracks of cars A and B. The detection of car C is clearly affected by interference and its track is created in the second half of the run-time.

VI. Conclusion

In this paper a simulator for multi-user radar scenarios was introduced. It was shown, that a complete system simulation including the tracking of objects is possible. The influence of interference on the tracking performance could be demonstrated for an exemplary scenario. With the aid of modern traffic simulators and the monitoring areas defined in Section III-B, it is now possible to perform automated performance tests of radar systems. In comparison to measurements the simulator has the great advantage of perfect reproducibility and a lower effort while its accuracy directly depends on the grade of detail in the description of the environment.

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