PC Based Real-Time Radar Environment Simulation

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***Abstract*— We present a Radar Environment Simulator (RES) that simulates the radar environment of a pulse Doppler radar in real-time. Hereby, the RES simulates pre-defined scenarios fully autonomously and interactively with the radar system. The RES generates digital I/Q signals containing radar returns of point sources, jammers and distributed clutter sources. Sophisticated physical models for point source RCS and Doppler, for jammer returns as well as for distributed clutter ensure a very accurate simulation of the radar environment. Because the RES is based on a high performance multicore PC platform consisting of COTS components, it is not only very compact and easy to transport but also cheaper than other traditional hardware based radar environment simulators. Additionally, due to the Software based signal generation, it is easy to extend and maintain.**

Keywords*— *High performance computing; multicore processing; pulse Doppler radar; radar clutter; radar environment simulation; radar test equipment.

I. Introduction

Modern radar systems use complex algorithms to adapt their scheduling as well as the waveform and frequency selection to the radar environment in real time. Cognitive radars even use machine learning techniques to improve this adaption. This requires interplay between many different parts of the radar, like signal processing, tracking and radar control.

In order to test such modern radars on system level, sophisticated test tools are required. Test tools are necessary, because in real life trials, the radar environment cannot be controlled. It is impossible to define test scenarios with characteristics that are exactly reproducible as well as specific enough to test single features of the radar under consideration. Furthermore, real life trials are much more expensive as compared to tests in a laboratory environment.

We present a Radar Environment Simulator (RES) which is a test tool that simulates the radar environment of a pulse-Doppler radar in real-time. As compared to other radar environment simulators built in the past, which consisted of a large number of processing boards, our RES only consists of one 19'' PC platform and thus is very compact and mobile. Because the RES uses COTS components and most of the computations are software based, the development and hardware costs are comparably low and the RES is easy to maintain and extend. Furthermore, the RES provides a very accurate simulation of the entire radar environment in real-time and interactively with the radar, which makes the RES more versatile and flexible than other test tools.

The RES consists of two components, the Offline Scenario Generator (SG) and the real-time RES (RT RES). With the Offline Scenario Generator scenarios are defined and pre-processed. A user enters all scenario parameters via a graphical user interface. Then, the input parameters are processed and prepared for real-time execution. The RT RES loads a pre-processed scenario and replays it. Hereby, it receives real-time information such as beam steering and waveform parameters from the radar, computes radar return signals based on the scenario and real-time parameters, and feeds these return signals into the radar. Apart from minimum user interaction when loading, starting, and stopping a scenario, the RT RES works with the radar fully autonomously.

Fig. 1 shows an overview of the RES system.

II. Main Features

The RES simulates point sources, distributed clutter, and jammer sources.

Point sources with arbitrary 3D trajectories can be simulated by the RES. Hereby, the RES uses a sophisticated RCS model. Apart from different Swerling scintillation models, the RES simulates the effects of multipath and aspect angle dependent multiple scatter interference. An accurate point source Doppler simulation including the effect of slow-time and fast-time Doppler allows for the generation of accurate return signals even for fast moving point sources such as rockets. Point source types simulated by the RES range from small artillery shells to ground vehicles and large targets like helicopters and aircrafts. The type of the point source as well as its trajectory and RCS characteristics can be specified by the user during scenario definition.

Complex distributed clutter models for ground, rain, insect, chaff and sand storm clutter are provided by the RES. For distributed clutter, the RES implements realistic physical models which include Swerling 1 fluctuation, an accurate model for Doppler shift and spread, and internal clutter fluctuation. Furthermore, attenuation effects of distributed clutter on point sources are simulated.

Finally, the RES simulates point source broadband white noise jammers with arbitrary 3D trajectories.

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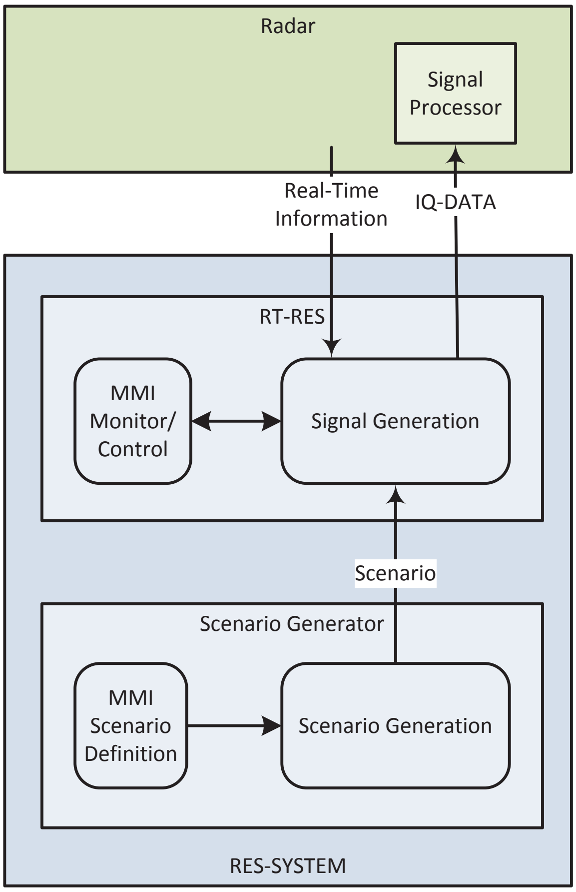

Fig. 1. System Overview of the RES.

All physical models are based on models given in standard radar literature; see e.g. [1], [2], [3]. These standard models have been adjusted and verified using real-life recordings made with a C-band radar.

The RES features scenarios containing over 700 point sources, up to 6 jammers and different distributed clutter sources in the radar beam at the same time. Hereby, the computation times for the generation of a scenario in the offline SG are of the order of a several seconds. In the RT-RES, the computation time of return signals for one burst of pulses is of the order of a few milliseconds.

III. Offline Scenario Generator

The Offline Scenario Generator is a software package with graphical user interface which allows for the definition of scenarios. The user specifies the radar position, point source types and trajectories, distributed clutter areas and characteristics, and general radar and scenario parameters such as the scenario simulation time. The SG then processes the user inputs and generates scenarios which are stored and can be loaded and executed by the RT RES. Because for the RT RES the computation time is limited, as many parameters as possible are precomputed in the SG and stored for use in the RT RES. Therefore, most algorithms are split up into an offline and a real-time part, where the offline part contains the main part of the computational effort. This splitting allows the RES system to implement sophisticated and realistic physical models for the simulation of the radar environment.

IV. Real-Time RES

The RT RES is a rack-mounted 19’’/4U high-end multicore PC platform with a PCI-Express FPGA board. The platform is shown in Fig. 2. The RT RES communicates autonomously with the radar in real-time and replays pre-defined scenarios.

Fig. 2. Hardware Platform of the Real-Time RES.

For each burst of pulses, the RT RES computes the radar return signals based on the active target, clutter, and jammer sources at the current scenario time, the current beam position, waveform, and transmit frequency. Hereby, the return signal is a digital baseband I/Q signal containing returns from the radar environment as well as the effects of the radar antenna and receiver. The return signal is then fed into the radar signal processor.

For the real-time generation of return signals, the RES proceeds as follows:

- For each burst of pulses, obtain information about the beam steering parameters and the transmit waveform and frequency.
- Based on scenario time and the beam position, select active point sources, distributed clutter sources, and jammers.
- Use the radar waveform and transmit frequency as well as precomputed parameters from the scenario for the current simulation time to compute the expected radar return signals.
- Feed the return signals into the radar signal processor exactly at the time when the signal processor would expect real radar returns.

Hereby, the processing of the input information given by the radar and the I/Q return signal generation is done by software. The computed signals are then passed on the FPGA board is responsible for the real-time communication with the radar. The FPGA receives triggers and clocks from the radar and sends out the expected signals.

This system architecture with software based signal generation and an FPGA board for the real-time communication with the radar keeps the hardware and development costs low and makes the RT RES maintainable and extendable. An overview of the signal generation in the RT RES is displayed in Fig. 3.

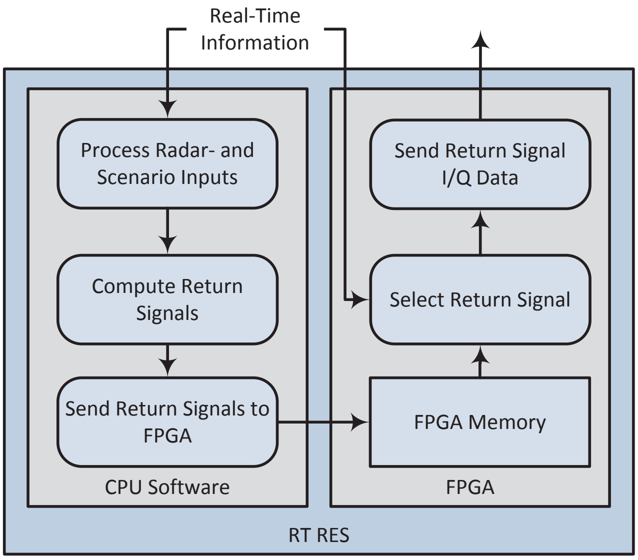

Fig. 3. Real-Time RES Signal Generation.

In order to be able to always provide the computed return signals on time, the RT RES has to fulfill firm real-time requirements. Furthermore, the computation time for each pulse burst is in the order of a few milliseconds. Due to these demanding performance requirements, both the hardware and software architecture of the RT RES have to be highly optimized.

In order to ensure the real-time capability of the hardware platform, custom-made low-latency PCI-Express drivers and a real-time low-latency Linux-based operating system which is adjusted to the specific hardware of the RT RES are used.

The RT-RES software used for signal generation is highly optimized and parallelized. The algorithms for the generation of radar return signals run parallelized on 12 CPU cores. In order to optimize the performance of each CPU core, the CPU's vector units are used. Furthermore, the data management of the software is designed to optimize the cache usage of the CPU cores. For the communication and synchronization of algorithms on different CPU cores, the RT-RES software uses optimized thread control and synchronization mechanisms.

V. SUMMARY

The RES is a universal test tool which can be used for a wide range of applications. Because of its compact hardware design, the RES is very compact and easy to transport. Due to its flexible hardware design with an FPGA board at the RES-radar interface, it can be adapted to work with different radars. Furthermore, it provides realistic return signals for a wide range of point source and distributed clutter types. The software based scenario and signal generation makes the RES signal generation algorithms flexible and easy to extend to new types of point and jammer sources and distributed clutter.

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