Comparison of SAR simulation concepts for the analysis of high-resolution SAR data

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Abstract

The simulation of SAR images provides valuable information used in many fields such as mission planning or the design of feature extraction algorithms. Simulation is in general a trade-off between achievement of approximation to reality as close as possible and minimization of computational load respectively processing time. For real-time application, a fast but suboptimal approach might be optimal, whereas for thorough parameter tuning of image processing or image analysis algorithms, more sophisticated methods would be required. In this paper, three SAR simulators using different simulation concepts tailored for a variety of tasks are introduced and the simulation results for simple building models and complex urban scenes are compared. To evaluate the realism of the simulation methods, the results are compared to a real SAR image of an urban scene. On this basis the possibilities and limitations of the different SAR simulation concepts are discussed.

1 Introduction

Analyzing urban areas using high-resolution SAR is a challenging task for a variety of radar remote sensing applications [7]. These include extraction of road systems and their current state, building reconstruction from multi-aspect SAR, monitoring of building activities in nuclear power facilities or excavation activities near pipelines or the detection of bridges destroyed by flooding [6], to mention only a few.

Any image analysis algorithm aiming at object detection and/or reconstruction relies on suitable object features to be found in the data. However, the appearance of real world 3d objects in the imagery is governed by many parameters, such as the 3d-2d mapping transformation according to the sensor principle, material properties and the chosen spectrum. Hence, a certain object may appear very different in the data and the choice of proper and robust features is a task far from being trivial. SAR simulations can assist in the selection of relevant object features in SAR images. Due to the complexity of urban areas, the SAR simulators should be able to process extended data sets in a short amount of time. Therefore, raw data simulators are often not applicable for image interpretation tasks which are bound to tight time constraints. Fast image simulators, either implemented using ray tracing or rasterization, provide simulation results in a short period of time. Of course, these fast results are only possible due to simplifications in the simulation process. For applications like mission planning or image analysis assistance, these simplifications are acceptable. However, if a detail analysis of very high-resolution SAR images of urban areas is intended, such approximations may not be well suited [3].

In this paper, the differences between the various simulation concepts and their results are analyzed. Three different simulation tools are introduced and a comparative study is conducted between the simulated images. In the next section a theoretical introduction to the assumed capability differences of the ray tracing and GPU based simulation concepts is given. In Section 3 the simulation results using a simple building model and a more complex scene are discussed. Finally, conclusions are drawn.

2 Ray tracing vs. rasterization

In computer graphics, rasterization is widely used in real-time applications. For SAR simulation, the rasterization approach is less feasible, due to the numerous multiple reflections occurring in SAR images. Ray tracing is a standard technique and despite the higher computational effort involved it is approaching real-time speed capability in some computer graphics applications. For SAR simulation ray tracing is established as standard technique used by a variety of software systems.

For realistic simulations of high-resolution SAR images of urban terrain, the software must be able to process complex building models. In order to represent the effects of small structures on the overall appearance of a SAR image, the building models ideally should contain a very high level of detail. This often

results in millions of triangles. For many simulators this is beyond the critical amount of data.
GPU based simulations are limited by the quantity of memory accessible by the graphics hardware. Assuming three 32-Bit values for the coordinates of each triangle point, three 32-Bit values for each of the three normal directions and one 32-Bit color value to describe the reflection properties, each triangle needs 76 Bytes. State of the art graphics cards support about 512 MB of memory and are therefore able to store approximately 7 million triangles. Besides the triangle information, the graphics memory also should be used for storing the simulation results and some interim results. Therefore, modern graphics cards can be assumed to be able to simulate scenes with about 5-6 million triangles.
CPU based ray tracing is not limited by the graphics memory but rather by the main memory, which currently is up to 2-4 GB with approximately 1-3 GB available for the ray tracing operation. If necessary, more triangles can be saved on the hard drive. This considerably slows down the simulation speed, but offers an almost unlimited amount of triangles that can be processed.
Besides processing speed, the quality of the simulation is important. Yet, even simulations of the highest quality have to be processed in an acceptable amount of time. The acceptable time span depends on the application. Ray tracing and especially raw data simulators deliver more realistic simulation results than rasterization based simulators. This is due to the missing multi-bounce reflection of the rasterization based simulators and due to the simplified backscattering model. Real multi-bouncing requires the rays to be traced through the scene. Furthermore, the reflection physics are usually implemented in a better and more realistic way in raw data simulators.
Therefore, the GPU based simulators are assumed to be less realistic but faster. In the next sections, indications for the validity of this assumption are given and the effect on the simulation results is analyzed. The usability of the simulation results for applications in SAR image analysis, considering these less realistic results, is also discussed.

3 Simulation results

The evaluation of the different building models is performed using the Oktal-SE simulator SE-RAY-EM [4] and the FGAN-FOM simulator as examples for ray tracing simulation systems and the SARViz simulator [1,2] as an example for a rasterization based real-time SAR simulation system. Table 1 gives an overview of the capabilities and limitations of the simulators. We concentrate on applications in urban areas and simulate building models of different complexities. First the simulation of a single building is shown, followed by a more complex urban scene.

Table 1: Features considered by SAR simulators: (+) considered, (o) only partly considered, (-) not considered.

Feature	SE-RAY-EM	FOM	SARViz
Layover	+	+	+
Shadows	+	+	+
Double-bounce	+	+	-
Multi-bounce	+	+	-
Materials	+	o	o
Speckle	o	+	o
Real-time	-	-	+
Raw data simul.	-	-	-

3.1 Simulation of a simple building

For a first comparison SAR images of a simple building model (Figure 1a) were simulated. The building was assumed to consist of one material (stone) and the surrounding area was assumed to be a grass plane.

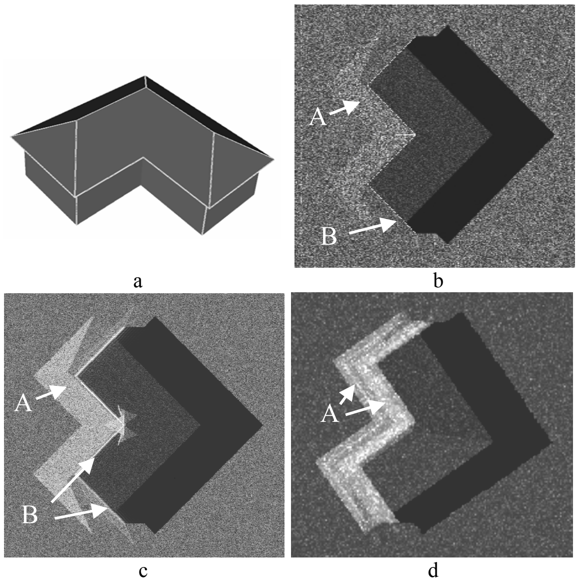


Figure 1: Simple building and SAR simulation. a) Model, b) SE-RAY-EM, c) FGAN-FOM, d) SARViz

The simulation results in Figure 1b and 1c show the roof structures as homogeneous areas (A), whereas the roof shown in Figure 1d has an inhomogeneous structure (stripes). Both SE-RAY-EM and the FGAN-FOM simulator model the dihedral corner reflection of the building walls (B) correctly, while these reflections are missing in the SARViz results due to the lack of double-bounce support. The backscattering from the building walls is much stronger in SARViz than in the FGAN-FOM simulator and in the SE-RAY-EM simulated scene. This is due to the different modeling of the materials.

3.2 Simulation of complex scenes

For simulation of complex urban scenes a test area in Munich, Germany, showing the campus of Technische Universität München (TUM), was chosen. A CAD model of the scene is shown in Figure 2. It consists of several closely agglomerated buildings.

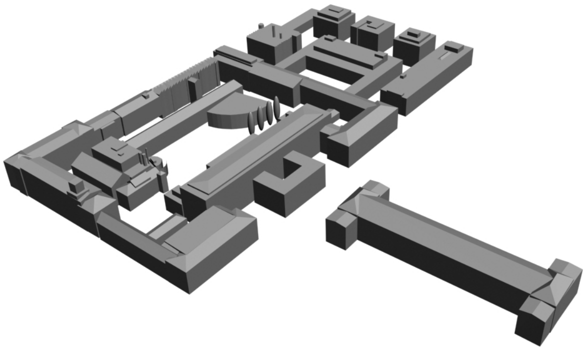
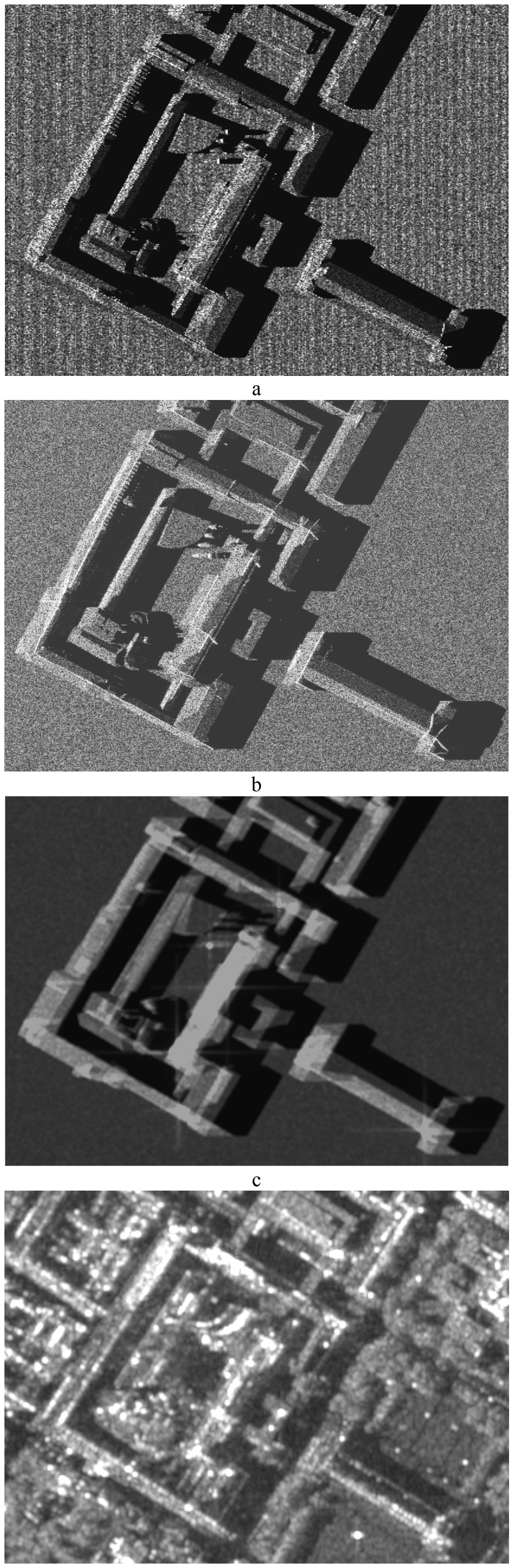


Figure 2: CAD-model of buildings (test area TUM)

Hence, a significant amount of multi-bounce signal propagation as well as mutual layover and shadowing effects are expected to be caused, involving building façade and superstructure elements and the ground of the yard. Figure 3 shows the real SAR image and the simulation results for the scene. Again, the buildings are modeled to consist entirely of one material, stone, while the ground is modeled by a grass surface.

As expected, simple SAR phenomena as layover areas and shadowed regions can readily be detected in the simulated images and their geometrical shape is very similar to the real SAR image. This is mainly due to the fact that these are geometrical phenomena and that the SAR geometry is correctly modeled by all simulators. The main differences are due to different modeling of materials and the absence of double-bounce reflections in the SARViz simulation. Thus, in the SAR Viz simulated scene no building corners are visible. This is a major drawback for using the simulation results with feature extraction algorithms because these often depend on the corner reflections of buildings. On the other hand, the real-time capabilities of SAR Viz provide the opportunity to show the scene from many different directions and off-nadir angles to detect occlusions and to determine the optimal flight parameters for further analysis, which would be very time consuming with both the FGAN-FOM simulator and SE-RAY-EM.

As for the modeling of the materials, SE-RAY-EM offers a very detailed description of the backscattering behavior of a wide range of materials, while the FGAN-FOM simulator provides a somewhat simplified model exploiting Ulaby & Dobsons tables [10] and SARViz models the backscattering behavior based on a modified Phong shading approach [5] also based on Ulaby & Dobsons tables.



a

b

c

d

Figure 3: SAR simulation of buildings (test area TUM). a) SE-RAY-EM, b) FGAN-FOM, c) SAR Viz, d) SAR image (ESAR, DLR-HR)

This leads to differences in the brightness of the corner reflections and in the appearance of the buildings. Due to the various local angles of incidence, the angular dependence of the backscattering plays an important role in urban scenes. Here the differences between the simulators are most obvious. The modeling of the backscattering coefficients for diffuse reflections seems to be quite similar in SE-RAY-EM and the FGAN-FOM simulator, while in SARViz layover areas appear much brighter. Specular reflections and dihedral corners at buildings are much brighter and more numerous in the SE-RAY-EM scene than in the FGAN-FOM scene.

All applied models are only approximations to the real SAR backscattering mechanisms. This has to be kept in mind when using simulated data for real SAR applications. Also, especially in urban areas, real SAR images are strongly influenced by a few very strong backscatterers due to small metallic structures. These are not simulated correctly by all three simulation tools since they exceed the level of detail provided by the CAD model. SE-RAY-EM does not simulate strong scatterers at all, while both SARViz and the FGAN-FOM simulator use a probabilistic approach to guess at the position of these scatterers that markedly alter the appearance of a real SAR image. Thus, for applications exploiting the intensities of the SAR image, a more detailed modeling of the materials and of the scenes will be needed.

Another major issue for the usability of simulated SAR images for SAR-specific applications is the correct modeling of the speckle effect. Since this effect dominates the SAR image statistics, many SAR-specific algorithms such as the edge extraction by Touzi [9] depend on the speckle of amplitude images to be Rayleigh-distributed. This can be modeled in different ways. One possibility is to multiply the calculated intensities with a number generated randomly according to the appropriate probability density function. This approach is used by the real-time simulation SARViz and by SE-RAY-EM. A further method is to distribute point scatterers randomly in each voxel and to add all signal contributions of these point scatterers coherently. The second approach is closer to the true formation of speckle in real SAR images and is adopted in the FGAN-FOM simulator.

4 Conclusions

SAR simulation tools can be used for a variety of different tasks such as mission planning or identification and quantification of relevant features for feature extraction algorithms. For most of the currently available SAR data, the simulations are sufficiently accurate to provide insight into the effects to be expected in real SAR images. Yet for high resolution images, the simulated results have to be used with caution. In data of this quality very small structures such as railings can lead to huge energy returns that dominate the image [8]. The real-time SAR simulation approach yields less realistic results but still the important layover and shadow areas are clearly visible. The SE-RAY-EM simulator has the most sophisticated backscattering algorithm taking various material properties into account. Comparing the results in detail is difficult due to the different material properties used.

Ray tracing systems deliver more realistic results, but the real-time simulation approach delivers fast results which are realistic enough for many applications. A combination of real-time simulation for a fast overview and ray tracing simulation or even raw data simulation for realistic results would be desirable.

The authors would like to thank the Microwaves and Radar Institute, German Aerospace Center (DLR), for providing the E-SAR image of Munich.

SE-RAY-EM was used by FGAN-FOM within a cooperation with Oktal-SE.

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