Using real-time SAR simulation to assist pattern recognition applications in urban areas

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Within the paper, the impact of current developments in urban modeling and graphics programming to the potential of SAR simulation and interpretation in urban areas is presented. As it will be demonstrated, SAR simulation is feasible in real-time even for complex urban environments by applying modern graphics cards. For this purpose, the SAR geometry is implemented using programmable graphics processing units (GPU), which are available as standard graphics hardware for 3D acceleration. Originally, the geometric models of urban areas, which provide the database for SAR simulation, were captured to generate realistic visualizations of virtual scenes. As it will be demonstrated, such area covering data bases can be modified to meet specific requirements of SAR simulations at different scales. Finally, the applicability of our SAR simulation as made available from off-the-shelf hardware components for the analysis and interpretation of SAR scenes by pattern recognition will be demonstrated.

Introduction

SAR simulators can assist pattern recognition algorithms by providing simulated data which is compared to real data sets for interpretation purposes. The respective algorithms for pattern recognition frequently refer to simulated data stored in large object databases. However, this approach is only feasible if suitable object spacing prevents an influence of the surrounding to the overall appearance. Since in urban areas the reflection of almost all objects is influenced by adjacent objects, pattern recognition algorithms in such areas should be based on simulations including these surrounding objects. Because of the complexity of urban environments and the huge amount of simulations needed to assist pattern recognition, a real-time SAR simulation is necessary. As it will be discussed within the paper, the more and more powerful and flexible graphics processing units (GPU) can be used efficiently to visualize SAR effects in real-time [1].

For simulation, 3D models of the respective environment are required. These models have to be detailed and realistic, especially if high-resolution SAR image simulation is aspired. In addition to detailed roof shapes, this can even require the geometric representation of the building façades. On the other hand, model simplification is acceptable for real-time simulations of large areas at small scales.

While the current state for the provision of urban geometry at multiple scales will be discussed in the next section, our approach for the real-time SAR simulation of complex urban areas will be presented in the following section. The use of the simulation results for building retrieval in SAR images will then be demonstrated in the final part of the paper.

Providing urban geometry

Geometric representations of the DTM surface and 3D building models, as required for SAR simulation in urban areas, are also used as input data for the visualization of urban areas. Due to the tremendous spread of these visualization applications in the context of urban planning or navigation, a large number of virtual city models are becoming available as standard data bases for a growing number of cities. For this purpose, the provision of complete sets of 3D building models at sufficient detail and accuracy is usually realized by the photogrammetric analysis of aerial images or airborne LIDAR.

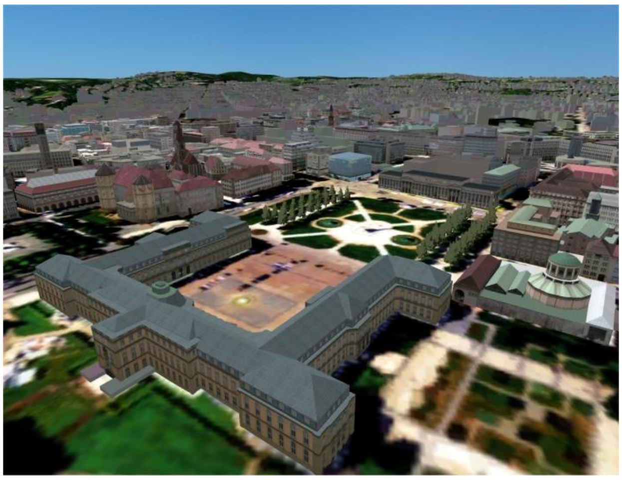

Fig. 1. 3D city model of Stuttgart with terrestrially captured façade textures

In our investigations, the 3D city model of Stuttgart is exemplarily used. This model, which is depicted in Fig. 1, provides the geometry of 36,000 buildings covering an area of 25 km^2. The data set is maintained by the city surveying office of Stuttgart and was reconstructed by a semi-automatic process, which combined ground plans and stereo measurement in aerial images [3]. Its overall complexity amounts to 1.5 million triangles. In addition to the majority of relatively simple building models, a number of prominent buildings like the historical New Palace (Neues Schloss) of Stuttgart are represented in more detail.

Simplification of building geometry

In order to reduce the computational effort during real-time visualizations of complex 3D scenes, surface simplification algorithms are frequently applied. This reduction of the number of triangular meshes, which are required to represent the respective 3D objects, is also advantageous for SAR simulation of complex urban scenes.

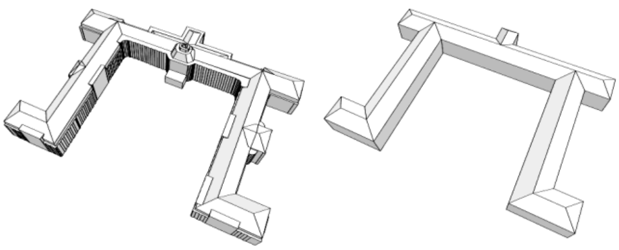

Fig. 2: Original and simplified 3D model of the New Palace (Neues Schloss)

If, like in our case, the geometry of buildings has to be simplified, a preservation of the respective characteristics, like parallelism or rectangularity, has to be guaranteed. This can be realized by our algorithm for the generalization of buildings [6]. An exemplary result of this approach is given in Fig. 2. There, the original model of the New Palace (Neues Schloss) is depicted on the left, while the generalized building is given on the right. Since the original model consisting of 2727 triangles was reduced to a simplified representation by 82 triangles, the computational effort during simulation is reduced, considerably.

Refinement of building façades

While the simplification of building geometries is advantageous for simulations of large areas at small scales, a geometric refinement can be necessary, if high-resolution simulations are aspired. Within available 3D city models typically used for visualization applications, the building geometry is limited to the extruded building footprints and the roof shapes. Like it is demonstrated in Fig. 1, façade textures are frequently mapped against the planar façades of the buildings to improve realism of the respective visualization.

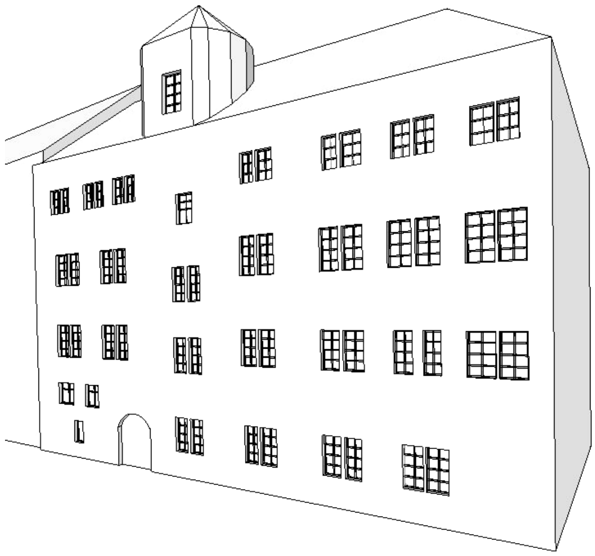

Fig. 3: Building model with reconstructed façade geometry

However, if the simulation requires the availability of façade geometry, a geometric modeling of elements like doors and windows can be necessary, like it is exemplarily depicted in Fig. 3. This type of information can be derived from densely sampled 3D point clouds collected by terrestrial laser scanning [4].

Real-time SAR simulation of complex urban environments

Real-time visualizations of urban scenes similar to Fig. 1 can be realized efficiently using a standard PC and commodity graphics hardware [7]. Similarly, our tool SARViz adapts methods originally developed by computer graphics to allow for real-time SAR effect visualization [1].

Of course, such radar images considerably differ from scenes acquired by passive sensor systems. As an example, in range direction the placement of objects depends on the distance between objects and sensor, while in azimuth, the SAR image geometry is based on the Doppler-Effect. The SAR geometry and radiometry is implemented using programmable graphics processing units. The geometry is adapted in the vertex stage of the graphics pipeline using so-called vertex shaders. The dynamically adapted geometry is piped into the fragment stage where pixel shaders calculate the radiometry. By further modifying these approaches, complex scenes, bi-static missions, or effects of moving objects can be visualized. Still, real-time visualization using graphics cards does have limitations. Current GPUs are based on rasterization. Unlike in ray-tracing, the paths of the rays are unknown. Therefore, multiple reflections cannot be visualized. However, these limitations are not crucial for most applications.

Implementing SAR geometry to programmable GPUs

The real-time SAR effect visualization tool SARViz is using methods developed by computer graphics to simulate SAR images. The GPU is processing triangles using local illumination. Each triangle is visualized independent from any other triangle. Each triangle point is processed by the so-called vertex shader, which treats the geometry. After the rasterization, the radiometry of each pixel is calculated by the so-called pixel shader.

Vertex shaders are highly specialized parts of a graphics card and are optimized for matrix calculations. Each point is transformed from the model coordinate system to world coordinates and then subsequently to screen or image coordinates. The imaging geometry of a SAR system is different in azimuth and range directions. In range direction the placement of objects depends on the distance between objects and sensor. In azimuth, the geometry is based on the Doppler-Effect. All of these effects need to be implemented in the vertex shader.

Afterwards the pixel shader is processing these pixels to compute the corresponding radiometry. Calculating the reflection intensity of SAR images is complex. For each pixel the corresponding face normal is determined using the 3D model. Taking material properties, like the dielectric constant, and sensor properties into account, reflection strengths can be calculated using the pixel shaders. SARViz offers three different methods of backscattering computation. From these three methods, the adaptation of the computer graphics methods is preferred, due to its computing time efficiency. According to the Phong reflection model [8] three illumination elements (diffuse, specular and ambient) are combined for the resulting reflection. Ambient lightning is negligible for SAR simulation. The diffuse illumination element is equivalent to the Lambertian reflection element. Combining the diffuse and specular elements, the SAR reflection intensity can be calculated. Finally the speckling is visualized by additive noise.

Simulation of large urban scenes

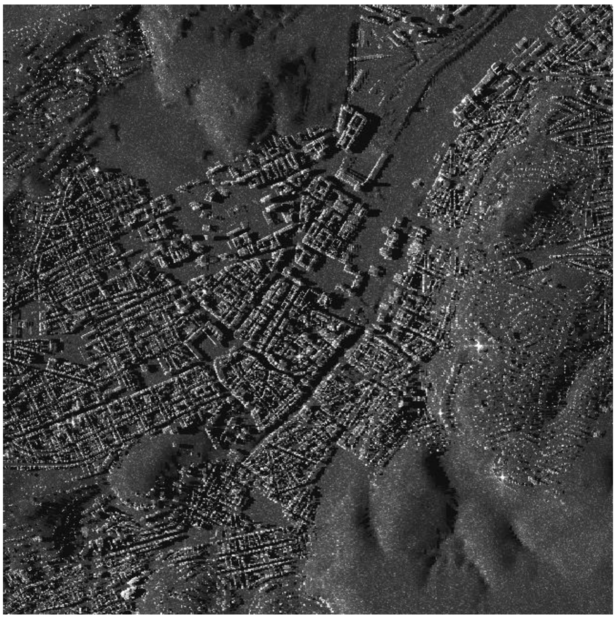

Fig. 4: SARViz simulation of the 3D city model of Stuttgart

A simulation of a complex urban environment is depicted in Fig. 4. As already discussed, the city model used for this example includes about 36,000 building models. The image simulated in Fig. 4 was generated in about 50 milliseconds using a "NVIDIA GeForce 7900 GTX" graphics card.

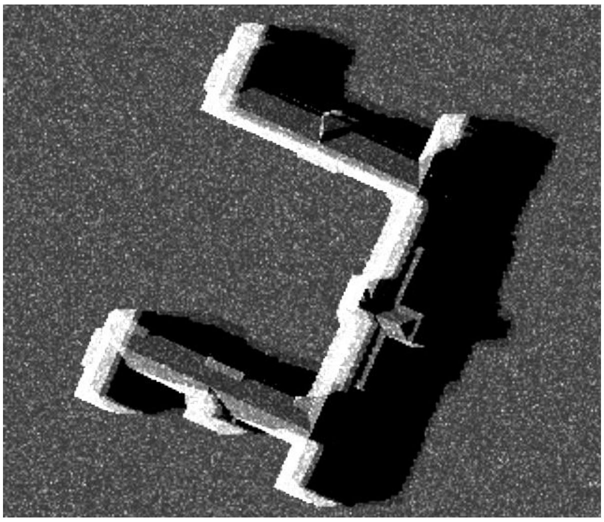

Fig. 5: SAR simulation of the original model of the New Palace (Neue Schloss) in Stuttgart

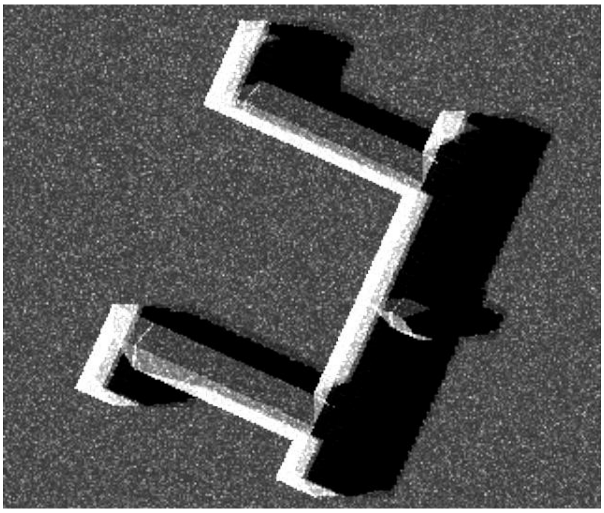

Fig. 6: SAR simulation of the generalized model of the New Palace (Neue Schloss) in Stuttgart

Similar to the real-time rendering of virtual scenes, the simulation performance can be further improved, by reducing the amount of triangles. Fig. 5 and Fig. 6 depict the simulation results for the 3D models shown in Fig. 2. Despite the simplified building geometry the results are still suitable for a number of scenarios.

High-resolution simulation

Modern high-resolution SAR images present an abundance of details which have to be taken into account by simulation based pattern recognition approaches. In addition to the real-time visualization of data sets covering large areas, SAR simulations should also be feasible for high-resolution sensors. For this purpose, very detailed models, as depicted in Fig. 3, should be made available.

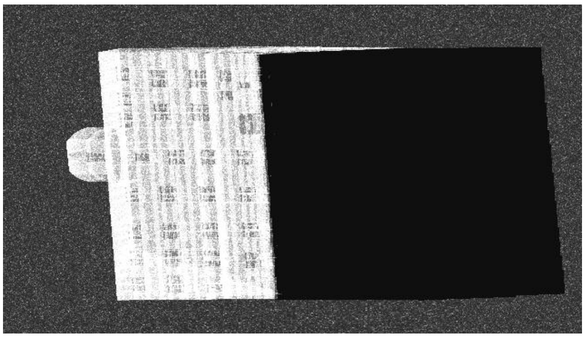

Fig. 7: SARViz simulation of a detailed building model

Fig. 7 demonstrates the simulation of the building model depicted in Fig. 3, with the windows and doors represented explicitly. The strong influence of the window geometry on the overall appearance of the building layover is clearly visible, proving the importance of high-resolution models.

Simulation based pattern recognition for building retrieval in SAR images

SAR simulations of 3D building models can be used to recognize and retrieve the position of special landmark buildings in SAR images. This technique can for example be used to improve the spatial reference of SAR images [2].

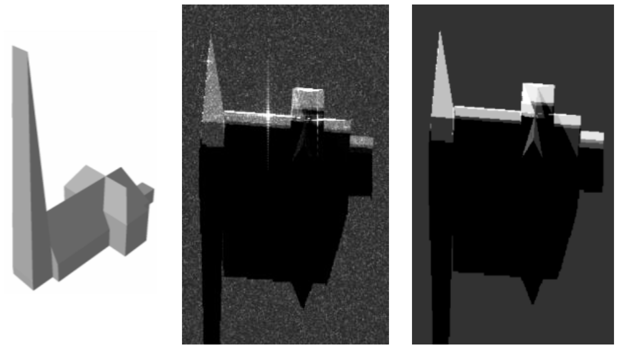

Fig. 8: 3D model (left) and SARViz simulation with (middle) and without (right) speckle of the St. Bernhardus church

SAR simulated 3D models provide expectation values, if they are simulated according to the properties of the real SAR image. For pattern recognition purposes, simulations without side lobes or speckling are preferred (see Fig. 8).

Fig. 9: Subset of a DOSAR image of Karlsruhe

In the SAR image subset showing a part of Karlsruhe (Fig. 9), the position of the church should be identified. By comparing the simulation and the real SAR image pixel-by-pixel, the position of the model can be determined. Using GPUs, this brute-force approach can be calculated astonishingly fast.

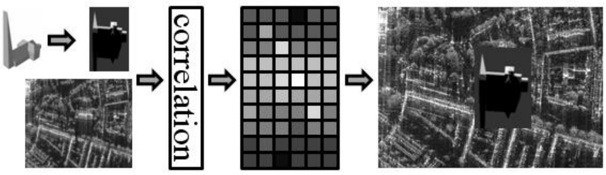

Fig. 10: GPU based position determination

Each simulation is calculated on-the-fly and kept as a texture in the memory of the graphics hardware. Afterwards the correlation process is using these textures as input data. The simulated image is pixel-wise correlated to the real SAR image. The correlations are calculated on down-sampled image subsets, each 64x64 or 128x128 pixels wide. In the final image each pixel represents the mean value of the overall correlation result between the simulated and the real SAR image. After copying this image back to the main memory, the pixel position with the highest correlation value can be determined. This method requires the pixel shader of the GPU to support a high number of commands per shader program. For large image subsets and a huge amount of correlations to calculate, another approach should be taken. Instead of calculating one value for each correlation step, a correlation image is calculated and this image is then reduced to receive one single value per correlation. For this purpose, the image is subsequently rendered with a fix mask size, calculating the mean value inside the mask, until only one value is left (see Fig. 11).

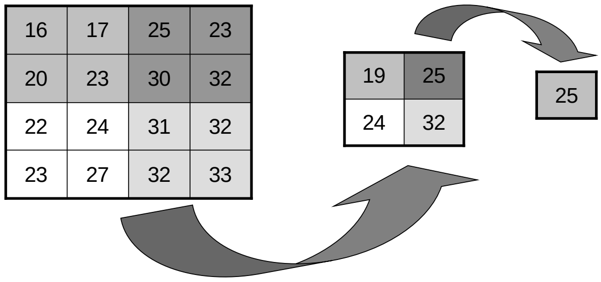

Fig. 11: Reduction to calculate the image mean value [5]

Conclusion

SAR simulation can assist various pattern recognition applications. Due to their speed, GPU based real-time SAR simulations can even assist brute-force techniques. However, simulation assistance for pattern recognition is limited by the quality and reliability of the available models. If high-resolution SAR image simulation is aspired, high-quality models are required. These models have to include the façade geometry. On the other hand low-resolution SAR simulations of large areas can benefit from generalized models.

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