Automated CAD Model Based Geo-Referencing for High-Resolution SAR Data Fusion in Urban Environments

Timo Balz, Institute for Photogrammetry, University of Stuttgart, Germany

Abstract

Fusion of SAR and optical images has to cope with the different imaging properties of both sensor types. In order to allow a meaningful data fusion, highly accurate geo-referenced images have to be provided. Based on CAD models of buildings, for example from available 3D-city models, simulated SAR images can be created using a SAR simulator. The correspondence between images of buildings created from a SAR simulator and the respective sections of unreferenced SAR images provides the required control point information. Using this approach an accurate geo-referencing can be achieved. The error in the initial reference of about 150m is reduced to around 1,5m. Even more, possible differences between the simulated image and the real image can be used for change detection applications.

1 Introduction

SAR based image interpretation in urban environments requires high-resolution SAR data to differentiate between the neighboured objects. Processing SAR in urban areas is difficult, even using high-resolution data, due to ambiguities, occlusions and side-lobes. Despite these problems, it is still possible to reconstruct buildings from InSAR data [1]. Data fusion is suffering from these problems, which are related to the sensor properties, too.

Data fusion is a prerequisite for automated GIS updating or change detection applications. Fusion of SAR with additional sensors like optical images requires accurate geo-referenced high-resolution data, especially in urban areas. Furthermore the different sensor properties of optical and SAR sensors have to be taken into account. The basic idea of the approach described in this paper is the geo-referencing of SAR data based on the automatic detection of SAR simulated 3D-models. Fusing high-resolution SAR data in urban environments requires spatial accurate data, but even using a spatially highly accurate SAR image, the different projections of the optical data and the run-time SAR data, has to be taken into account, for instance by using a SAR simulator.

The simulated SAR image of the building model is compared to the real image. The SAR image is referenced using this comparison. Furthermore the simulated images of the 3D-city model can be used for change detection.

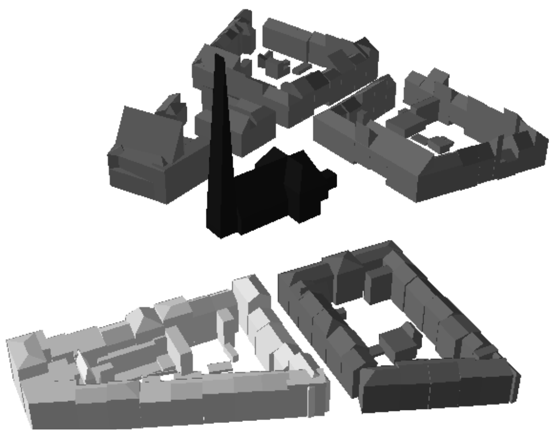

Fig. 1 Subset of the 3D-city model from Karlsruhe

2 SAR-Simulation in Urban Environments

A SAR simulator is a key tool for the analysis and interpretation of SAR data [2]. Furthermore, simulations are useful during mission planning, for example to avoid occlusions, especially in dense urban environments [3]. The simulation of urban environments is different from the simulation of natural environments, since the different backscattering behaviours [4].

Using the SAR View Light (basis version) simulator, provided by the EADS Dornier GmbH, the subset of the 3D-city model of Karlsruhe shown in **Fig 1**, which has been created using LIDAR and GIS-information [5], was simulated.

City-models are generalized and simplified representations of the reality. The differences between the model and the reality will always result in incomplete and wrong simulation results. Moreover the simulator can not handle all the possible SAR effects. The model in **Fig 1**, for example, contains only buildings and even those can be incomplete and erroneous, like for example the spire. Beside the wrongly shaped

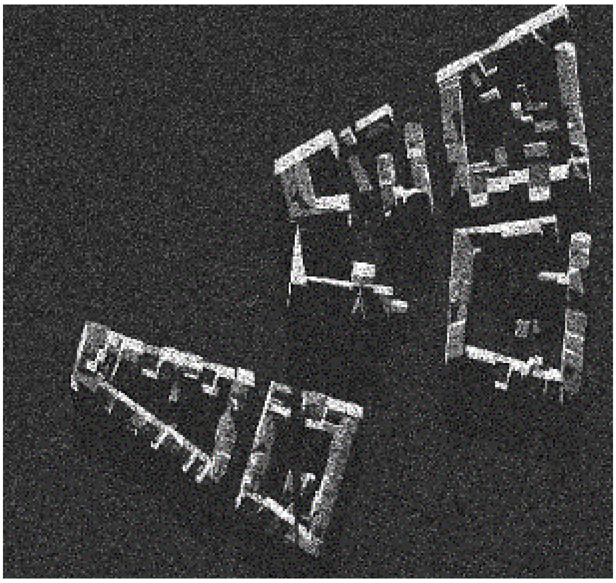

Fig. 2 SAR simulation of the city model

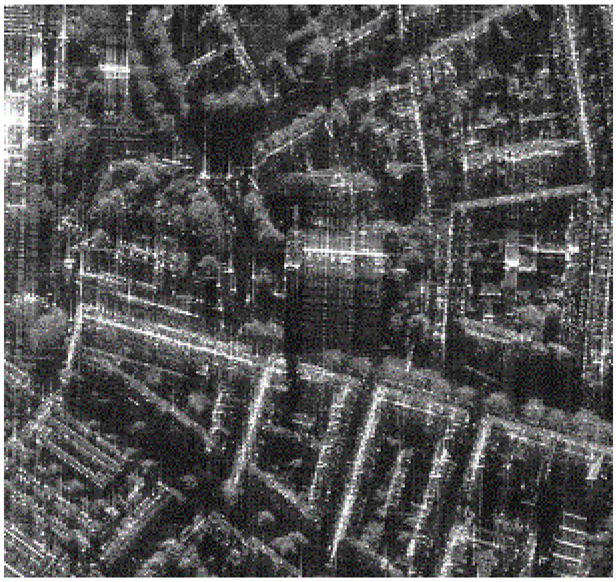

Fig. 3 DOSAR image of the simulated area (EADS Dornier GmbH)

spire, the position of the whole church is about 1m wrong. Therefore the resulting simulated image (**Fig 2)** must be different from the real image (**Fig 3**).

Beside the imperfect models, corner reflectors and their strong side lobes are a great problem analysing SAR data. It is not possible to precisely forecast the appearance of corner reflections, thus corner reflections can massively disturb the automated geo-referencing. For this reason it most important to detect regions influenced by side lobes.

This can be realised by filtering the data in the frequency domain. Doing this it is possible to partially detect the side lobes. According to the squint angle a wedge filter is applied on the Fourier image. Comparing the filtered image with the original image the side lobes can be detected. Such a filter is easy to implement, showing acceptable results, but is not perfect.

3 Object Detection

The most important step of the geo-referencing approach described in this paper is finding corresponding object- and image points. The orientation of the SAR data is assumed to be available from the flight data. 3D-GIS data from the area of interest is required as reference data.

3.2 Simulated Models for Object Detection

As first step, special landmark buildings have to be selected by an operator in the GIS-data. It is possible to automatically select the landmark buildings by analysing the 3D-GIS data. These buildings should be separated from other buildings, to avoid them from merging together. Furthermore they should have specific properties which have to be different from the surrounding buildings. As an example a DOSAR image showing the area of Karlsruhe has been used. DOSAR is the multifrequency polarimetric airborne SAR system of the EADS Dornier GmbH. The flight direction is 90.05°, the off-nadir angle is 70° and the 3dB resolution is about 0.57m. The St. Bernhardus church, which can be seen as black building in **Fig 1**, was chosen as landmark building.

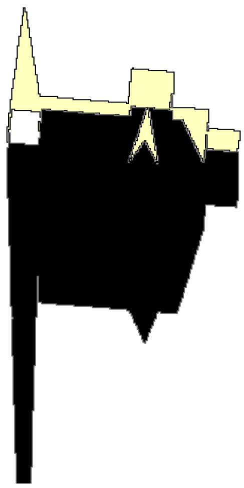

Fig. 4 Vector representation of the simulated SAR image of the St. Bernhardus church

The chosen building has to be found in the SAR image using the simulated image of the model. For this reason the model of the church was simulated without any speckle, according to the data of the real flight. The simulated image is then transformed in the vector representation, which only consists of bright areas and shadow areas (**Fig 4**). The vector representation has some advantages over the pixel representation, especially in handling large areas and using multi-scale approaches. The SAR data is converted to vector polygons using an adaptive threshold segmentation [6]. This is done on multiple pyramid levels for multi-scale analysis.

3.3 Search in the Real Data

The size of bright regions in simulated and real data is compared to find corresponding areas. During this analysis only the area of bright regions are considered and neighbouring bright polygons with similar values are merged. This search is done on different scales, starting at the lowest scale. This multi-scale approach reduces the amount of considered polygons and the error rate.
The whole testing area consists of 40505 segments in the largest image scale. This simple search method, reduced the possible regions representing the church position down to three segments. These positions are then analysed by comparing pixel-by-pixel the simulated image to the real image. The point with the highest correlation is assumed to represent the correct position. This is a very time consuming process, but because only three segments have to be examined, it is acceptable.

3.4 Geo-referencing

One corresponding coordinate pair per simulated object can be acquired this way. Assuming flat terrain and an affine transformation, this is sufficient, because the pixel size and the direction of the flight is known. For transformations requiring more corresponding points, more landmark buildings have to be used.
The accuracy which can be achieved using the presented approach is difficult to determine. The area around the St. Bernhardus church was referenced and the result compared to an orthoimage. Not many points are directly comparable, because only points which are detectable in both images and which are near the ground level could be used.
The estimated accuracy is around 1,5m in the vicinity of the church, which is equivalent to 6 pixel of the SAR image or 3 times the 3-dB resolution of the SAR data. This accuracy is achieved by using only the church model, which is quite erroneous. Compared to the error of 150m, using only the internal spatial reference, the result is promising.
This automatic approach is comparable to a manual referencing, because even for experienced operators it is difficult to find corresponding points using SAR and optical data. In **Fig 5** the automatically georeferenced SAR image is compared to an orthoimage generated from an aerial image. The railtrack fits rather well in both images, indicating the good georeferencing. In **Fig 6** the geometrical properties of SAR concerning 3D-objects. The layover of the building is imaged in front of the building, but the edge of the building is corresponding to the far-range end of the bright area. A great amount of energy is returned by the kerb, which for example may also disturb any automatic object identification.

Fig. 5 DOSAR image (left) and orthoimage (right)

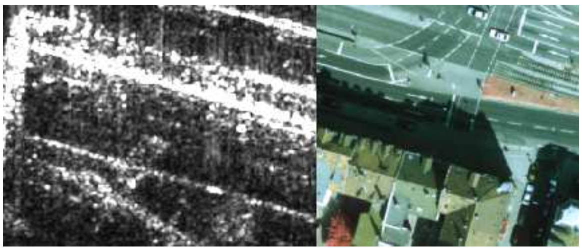

Fig. 6 DOSAR image (left) and orthoimage (right)

4 Data Fusion

For a useful data fusion in urban environments it is not sufficient to just combine the reflectance values from different sensors. Fusing SAR images with optical images or GIS data, the geometrical properties of the sensor has to be considered, especially while dealing with 3D objects.

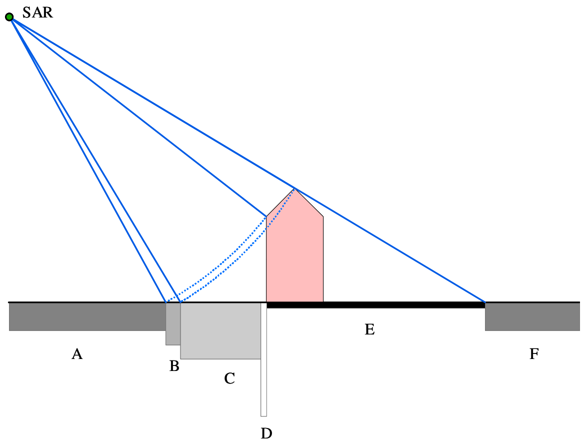

Fig. 7 SAR geometry

The building shown in **Fig 7** is standing separated and is surrounded by grassland. A meaningful fusion of the grassland is only possible in the areas *A* and *F*. In the other areas the layover and shadow of the building disturbs the reflectance values of the surrounding grass. The reflectance values of *A* and *F* can be combined with the optical information, for example to improve land-use classifications, but dependent on the application, the information from the areas *B*, *C*, *D* and *E* has to be treated differently.

4.2 Data Fusion for Change Detection Applications

A typical application in urban environments is change detection. In this type of application it is not necessary to investigate every pixel, rather a set of objects is considered. One object can for example be a building block. Analysing buildings, the areas *B*, *C*, *D* are often difficult to separate, thus these bright areas are considerer as one area. Changes in these areas are important, because the length of these areas in range can be used to analyse the height of the object [7].

4.3 Data Fusion Example

After the successful detection of the church, the SAR data around the church is roughly geo-referenced. The building block to the south-west, marked white in **Fig 1,** is used as an example for the supposed data fusion for change-detection. Because of possible topographic effects, the accurate position of the block is not known exactly yet. Therefore the simulated model of the block is searched in the image. This search method is similar to the search of landmark buildings described in chapter 3, but because the position is already at least roughly known, only the pixel-wise search is used. The referenced data can now be used for different applications. In **Fig 8** the simulated image is overlaying the real image. The peak areas are red and the shadow areas are transparent, therefore only dare areas of the real image should be visible.
Trees and some objects are still visible inside the assumed shadow area, due to the incomplete city-model. In the boundary area some neighbouring buildings are sticking out of the supposed radar shadow. Beside the incompleteness of the model no big changes are visible. Areas which are bright in the simulated image but are not in the real image are indicating missing objects. Data fusion for land-use classification is only useful in the black areas of **Fig 8**, because these regions are not influenced by the building block. The reflectance values in these areas can be directly fused to reflectance values from different sensors, presuming these areas are not influenced by 3D-objects not included in the used city-model.

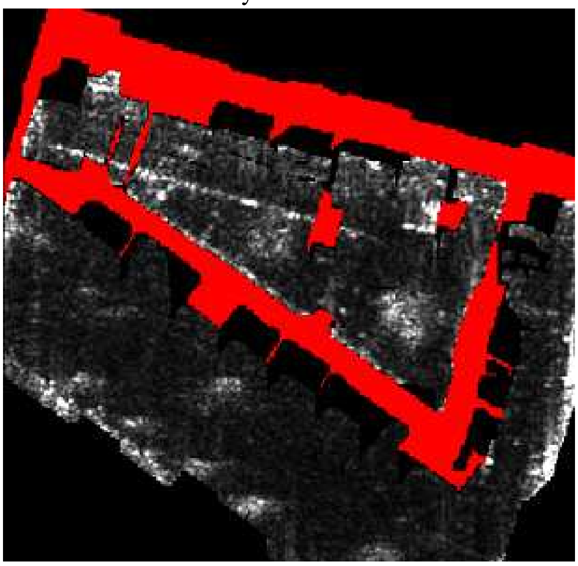

Fig. 8 DOSAR image overlaid, for change-detection purposes, with the geo-referenced simulated SAR image

5 Conclusion

SAR-simulating available 3D-city models and comparing the results to the real image is an useful way to automatically geo-reference SAR images. The initial error of about 150m was reduced to 1,5m, although the geo-referencing was based on an erroneous model. Not too many objects of the city model are allowed to change, but if the geo-referencing is successful, the simulated model can afterwards be used for comparing the model with the more up to date data.
Unfortunately the side-looking sensor principle of SAR is unfavourable for urban environments, compared to aerial imagery or LIDAR. Occlusions can often prevent any detection and ambiguities can disturb the change detection, therefore sometimes change detection applications using SAR are not possible at all. Anyhow, for time-critical applications SAR is still the best or only alternative under bad weather conditions.

6 Acknowledgement

We thank the EADS Dornier GmbH for providing us with the simulated and real SAR data and for their help in making this work possible.

7 Literature

[1] Sörgel, U.: Iterative Verfahren zur Detektion und Rekonstruktion von Gebäuden in SAR- und InSAR-Daten (in German). PhD-Thesis, University of Hannover, 2003
[2] Leberl, F.W. and Bolter, R.: Building reconstruction from Synthetic Aperture Radar images and interferometry. In: Baltsavias, E.P., Grün, A., and Gool, L.v.: Automatic Extraction of Man-Made Objects From Aerial and Space Images (III). Lisse, 2001
[3] Sörgel, U. , Schulz, K., Thoennessen, U., and Stilla, U.: Event-driven SAR Data Acquisition in Urban Areas Using GIS. GIS 16 (2003), No. 12, pp. 32-37
[4] Franceschetti, G., Iodice, A., Riccio, D., and Ruello, G.: SAR Raw Signal Simulation for Urban Structures. IEEE Trans. on Geoscience and Remote Sensing 41 (2003), pp. 1986-1995
[5] Haala, N. and Brenner, C.: Extraction of buildings and trees in urban environments. ISPRS Journal of Photogrammetry and Remote Sensing 54 (1999), No. 2-3, pp. 130-137
[6] Levine, M.D. and Shaheen, S.I.: A modular computer vision system for picture segmentation and interpretation. IEEE Transactions on Pattern Analysis and Machine Intelligence 3 (1981), pp. 540-556
[7] Kirscht, M. and Rinke, K.: 3D Reconstruction of Buildings and Vegetation from Synthetic Aperture Radar (SAR) images. In: MVA, IAPR Workshop, Japan (1998)