Geocoding and fusion of airborne high-resolution multi-aspect SAR data

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Abstract

The advent of high-resolution SAR imagery gives rise to the need of precise geocoding of the data, e.g. for data fusion. This requires a high resolution DEM. Especially in urban areas, the DEM should include elevated objects like buildings in order to assure a mapping of the SAR data to the right geoposition. Erroneous navigation data leads to an incorrect recorded sensor track. Based on a DEM, the true sensor track can be reconstructed. A prerequisite is the referencing of DEM and SAR image data. The detection of tie points between the DEM and a SAR image is often difficult. In our proposal, tie points are generated by matching simulated shadow areas (based on a high resolution LIDAR DEM) with potential shadow regions (dark regions) in SAR images in the slant range geometry. After a first coarse geocoding, the set of multi-aspect SAR images might not be perfectly co-registered. This misalignment is corrected by a fine registration, using edges, which were detected in the slant range images.

1 Introduction

Precise geocoding is a prerequisite for any fusion of remote sensing data. For SAR sensors like ERS 1 the mapping of the SAR data on an earth ellipsoid [8] is often sufficient, if the terrain is flat. In case of undulated terrain, such an approximation of the earth's shape by an ellipsoid results in large errors. In order to

achieve a higher precision, the scene topography has to be considered in the geocoding approach. Information of the bare earth height of the scene is provided in digital terrain models (DTM). Based on the data acquisition parameters (e.g. track, depression angle), the SAR image pixels can be mapped on the correct DTM position according to the so-called Range and Doppler equations [7]. The sensor track is determined from the carrier navigation data. Due to the side-looking SAR illumination, even small deviations of the navigation data from the true sensor position and pose might lead to large offsets on the ground. Hence, usually a pre-processing step is required before the mapping. Using tie points connecting structures in the DTM to the SAR image the real sensor track is estimated [4]. Because of the complementary scene information contained in SAR images and DTM, it is often difficult to identify corresponding structures even for SAR experts. Simulation approaches have been proposed for satellite SAR data to overcome this problem: tie points are automatically matched by a correlation of the real and the simulated data. Such simulations are usually based on geometric scene properties [6]. If information about the terrain class (e.g. forest, grass, rocks etc.) is available, the radiometric dependency of the backscatter on material properties can be considered [4], based on empirical statistical models [11].

The mentioned approaches work well for rural or alpine areas and SAR data with coarse resolution. In case of high resolution SAR data of urban scenes, the geocoding methodology has to be adapted for mainly two reasons. Firstly, elevated objects on the ground, e.g. buildings and trees, have to be considered. In order to map those on the correct position, the geocoding should be based on a digital elevation model (DEM) rather than on a DTM. Secondly, a partitioning of the scene in object classes according to radiometric properties alone is not appropriate, because the geometric structure of man-made objects dominate the appearance of urban scenes in SAR imagery. For example, a certain building may look very different in SAR images, even for small aspect or off-nadir angle variations. Furthermore, often no ground truth is available concerning the material diversity of man-made objects, e.g. rooftop materials (tiles, concrete, tin etc.). The latter point limits the realistic appearance of coherent SAR simulations for urban scenes [3], because micro scale object properties, like dielectric constant or roughness compared to wavelength, can not be modeled. Based on a CAD model of the scene, geometrical effects like dominant scattering at building edges or multi-bounce propagation can be approximately modeled using ray-tracing techniques [8]. Both, coherent simulations and ray tracing, lead to computational load and may be not suitable in case of large scenes or multi-aspect high-resolution SAR data.

In this paper, an automatic approach for geocoding and data fusion of high-resolution multi-aspect SAR amplitude images is proposed. In a first step, the SAR images are coarsely geocoded by correlating dark image regions with simulated shadow areas predicted from a high-resolution LIDAR DEM [10]. Their centers of gravity serve as tie points. The fine registration is carried out by matching edges, which were segmented in the slant range images. The approach is demonstrated with the data fusion of a pair of airborne high-resolution SAR images of an airfield.

2 Approach

The workflow of the approach is depicted in Fig. 1 and is divided in two main steps. First, a coarse geocoding is performed using shadow structures followed by fine registration based on image structures (edges) in the SAR images.

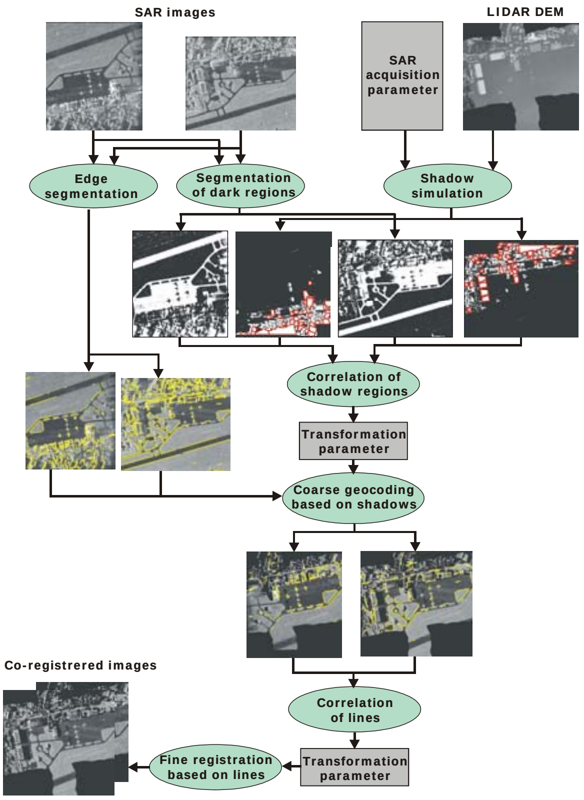

Fig.1 Workflow of the geocoding approach

Based on a high-resolution DEM and the given initial data acquisition parameters, a simulation is carried out, in order to estimate where shadow areas appear in the slant range geometry. In the corresponding slant range SAR images connected dark regions are segmented. Hypotheses of corresponding pairs of shadow regions in both sets are determined by correlation. Blunders in the assignment process are identified and eliminated with a statistical method. Then the different SAR images are transformed into a world coordinate system, together with symbolic features of man-made objects in the images like edges, lines, and corner structures.

The geocoding accuracy is now in the order of some meter relative to the DEM. Based on the mentioned object structures, a fine registration of the SAR imagery is carried out.

After the registration a data fusion is carried out. In any case, layover effects can be corrected and occluded regions can be filled. In the following sections, these steps are described in more detail.

2.1 Image – Simulation Matching

The simulation process uses a so-called „incoherent“ method [7] to predict shadow areas. The simulated shadows are caused from elevated structures like buildings, trees, and some airplane shelters.

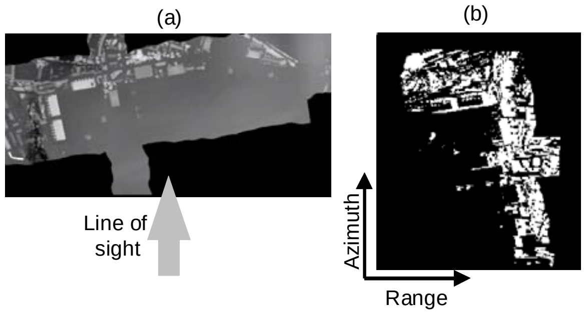

Fig.2 Shadow simulation process: a) LIDAR DEM. b) shadows in slant geometry (shown in white).

The approach is restricted to a geometric analysis of the LIDAR DEM (first-pulse mode, Fig. 2a), which is sufficient for our purpose.

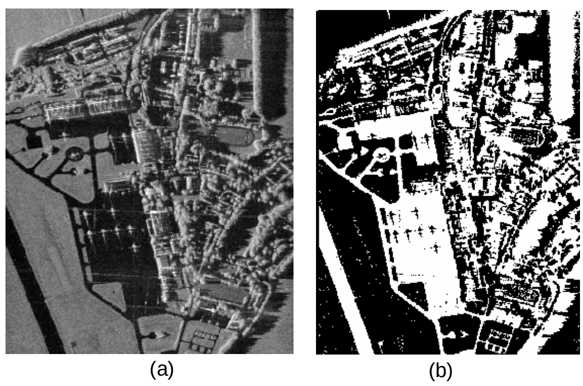

Fig.3 SAR image segmentation: a) the original image, b) the segmentation result (segmented dark regions are depicted white).

Outputs are the simulated shadow areas (shown white in Fig. 2b) and the mapping function between the slant geometry of the simulated shadow image and the DEM.

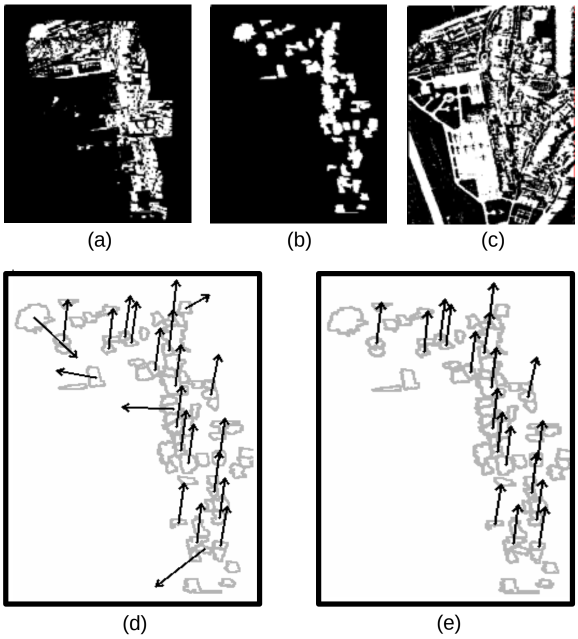

Fig.4 Result of the correlation: a) all simulated shadows, b) the selected reliable shadows, c) dark regions in the SAR image, d) all correspondences, e) RANSAC-filtered correspondences.

For the extraction of possible shadow areas in the original SAR-image, dark regions are segmented using a gray-level threshold. This threshold is derived from a histogram analysis of the SAR image (X-Band, approx. 1m resolution, Fig. 3a). As it can be seen in Fig. 3b, this method of course extracts not only shadow areas but also other regions of weak backscatter (e.g. asphalt-areas).

The matching of the dark regions in the SAR-image and the simulated shadows is based on binary correlation. From the set of simulated shadow regions (Fig. 4a) only those regions are chosen for correlation (“reliable” shadows, Fig. 4b), whose size matches the expected typical area of a shadow cast from a building or a group of trees.

A correlation result of the binary images shown in Fig. 4b, and 4c is illustrated in Fig. 4d: The contours of the reliable shadows are depicted together with an arrow pointing to the correspondence. A trend is clearly visible, but there are blunders as well. In order to exclude the blunders, a post-processing step is required. For this purpose the RANSAC algorithm (RANdom SAmple Consensus [2]) is used. The remaining correspondences after the optimization, which are used to determine the transformation parameters, are shown in Fig. 4e.

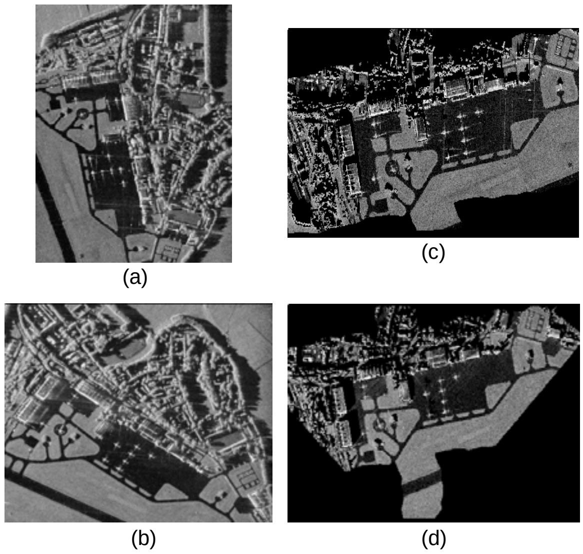

Fig.5 Result of the geocoding step based on Image-Simulation-Matching: a),b) original SAR-images. c),d) in world-coordinate system projected images**.**

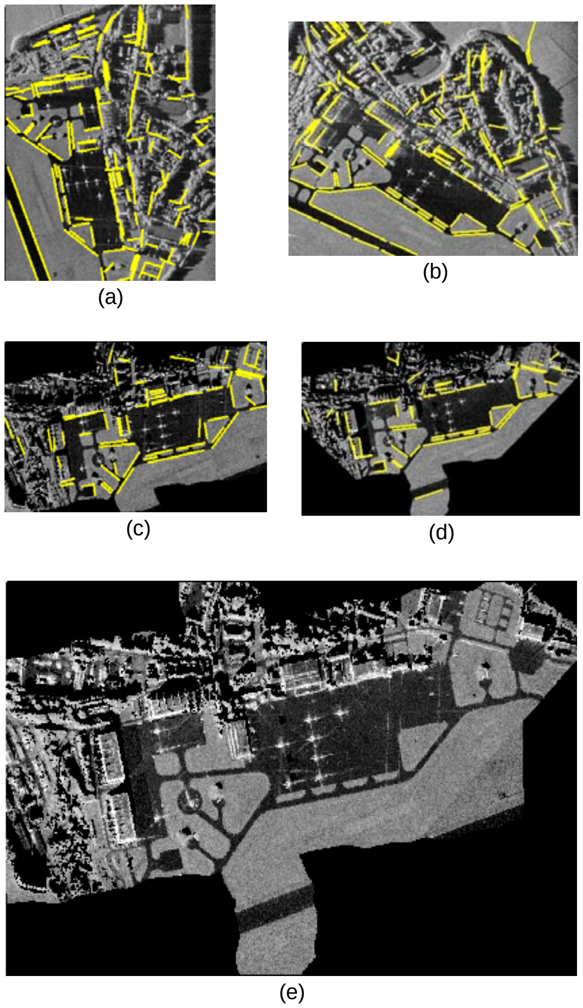

Fig. 6 Fine registration of two images based on edges: a), b) the original images with the in slant-geometry segmented edges, c),d) the edges projected on DEM, e) fusion of the two images.

The resultant global transformation in the slant range compensates most of the initial errors of the navigation data. With the inverse of the simulation mapping function, the transformed SAR image is projected into the DEM geometry (world-coordinates). These steps are done independently for all SAR-images. An example for two different aspect angles is shown in Fig. 5.

2.2 Image – Image Matching

After the coarse transformation of the SAR images into the world-coordinate system, the remaining misalignment of SAR images is in the order of some meters. This can be corrected with an additional fine registration step. Due to the strong aspect-dependency of SAR, an image correlation of the transformed SAR images might fail. For example, shadow regions and dominant scatterers appear at different locations in multi-aspect images.

Hence, the fine registration is not carried out at the iconic (image) level, but at the symbolic (object) level. Here, linear edge structures have been segmented in the original slant range images (Fig. 6a,b). The segmentation in these images is advantageous, because there are no distortions caused by the geocoding process (e.g. interrupting of straight edges). Then the edges are transformed into the world-coordinate system according to the same transformations as the SAR images (Fig. 6c,d). For the matching of the lines, a fast statistical method [5] is used. Fig. 6e shows a fusion of the two SAR images after the fine registration. The resulting image is larger than each of the initial images. In case of competing pixel, the brighter one was chosen for this visualization.

3 Conclusion

The geocoding of high-resolution SAR imagery of urban scenes requires height data of comparable resolution, which should represent elevated objects like buildings. A first-pulse LIDAR DEM is well suited for this task, because it contains buildings and trees. Using a simple shadow simulation, the main navigation errors can be compensated. However, for image fusion purposes a subsequent fine registration is required. In the future work, the geocoding of multi-aspect SAR images shall be carried out in an iterative manner. Furthermore, the incorporation of other data (e.g. ortho images) for tie point selection will be investigated.

4 Acknowledgment

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5 Literature

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