INVESTIGAGTIONS ON SPACE-BORNE SAR TOMOGRAPHY FOR STRUCTURAL ANALYSIS OF FORESTED AREAS

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1. INTRODUCTION

Remote sensing systems are of great interest to gain geospatial information in forest environment. In particular, Synthetic Aperture Radar (SAR) which is an active and coherent imaging technique is commonly used from aerial and satellite platforms. Microwave pulses are emitted by a transmitter and their echos reflected from objects on ground are coherently recorded and processed in such a way, that the resulting 2D data matrix is showing the specific reflectance of the sensed ground objects in form of an intensity image. Since SAR is a coherent technique, not only the measured intensity of the illuminated objects is available, but also the phase information.
Depending on the application different kind of SAR processing strategies can be used, like Interferometric SAR (InSAR), Persistant Scatterer InSAR (PSI), and the recently developed SAR tomography. SAR tomography inherits its name from the well-known principle of tomography in medicine. While medical tomography is a 3D sensing technique for estimating the volume scattering of a human body, the SAR analogon does the same for remote sensed natural objects. To reconstruct the 3D scattering distribution of the objects, a series of space-borne SAR images - each image capturing the same objects but sensed from a slightly different orbits - are coherently combined in such a way, that the resulting function gives an estimate of the objects volume scattering or the number of prominent scatterers inside one resolution cell.

2. STATE OF THE ART AND CHALLENGES

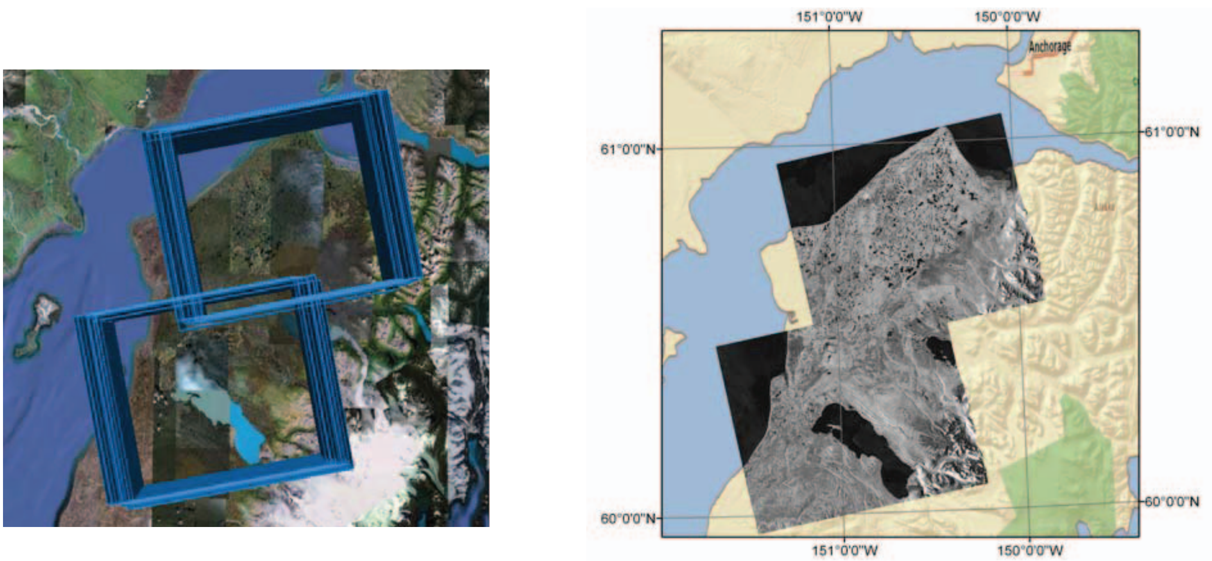
While conventional SAR is a 2D imaging technique, which captures the scattering behaviour of surfaces by discrete features, like range or reflectance, the principle of SAR tomography enables the estimation of a 3D scattering distribution. Concerning this, a variety of novel analyses methods can be introduced.
This new processing techniques is especially of interest in regions containing dense structured 3D objects like vegetation areas, where penetration by radiation is uncertain due to the scene composition. Depending on the density of the vegetation and the wavelength of the microwave radiation partial penetration is possible. Thus, a common 2D image cannot fully represent the scene characteristics, while SAR tomography is able to resolve 3D scattering. After raw data is acquired the volume scattering distribution inside the observed object regions has to be calculated to allow an enhanced reconstruction of vegetation objects, like trees, bushes or other vegetation

types. While the mathematical concept of SAR tomography is already established [1] and successfully applied to vegetated areas for the airborne case [8], the comparison of simulated and real tomographic data stemming from satellite SAR images is currently investigated for X-Band data [2] and needs further analyzed for L-Band space-borne data, especially for applications such as estimation of tree heights, vegetation density, and biomass in general.

For firm objects causing surface scattering such as buildings, roads and other infrastructures, space-borne SAR Tomography allows to resolve the so-called layover scattering. This layover effect appears, if two or more scattering objects had same distance to the SAR sensor. In Thiele et al. [3] the layover phenomenon on gable-roofed buildings was investigated, whereby the ground, the building wall, and building roof show the same distance. Consequently, the contributions of these three are mixed, and impede a separation of these objects in the resulting SAR image. Since tomography reconstructs the reflectance function in 3D, a separation becomes possible [4].

The estimation of the tomographic profiles can be accomplished with model-based estimation algorithms such as MUSIC and CAPOON or with model-free spectral estimation techniques. The advantage of model-based algorithms relates to their capability of estimating the influence and location of contributing scatterers with better resolution compared to model-free algorithms. However, the number of scatterers needs to be set in advance to initialize these algorithms or estimated via model selection schemes [9]. In view of the available resolution of space-borne L-band imagery, the application of model-free algorithms seems currently out of sight, yet not so for model-based schemes.

3. TESTSITES



A b

Figure 1 Google optical images overlaid with Geo-position of SAR data stacks (a) and topographic map overlaid with one SAR image of both data stacks (b)

The general goal of the study will be the retrieval of vegetation parameters, such as height, density, and distribution by utilizing tomographic methods. For our investigations data from the ALOS (Advanced Land Observing Satellite) PALSAR sensor will be used. Our forest test site located in Alaska, USA, two ALOS image stacks have already been acquired (Figure 1). Additional ground truth data provided by colleagues from University of Alaska Fairbanks for evaluation are available, too.

4. METHODS AND STUDY

The goal of this study is to improve sophisticated tomographic algorithms for estimating different layers of vegetation in 3D. To this end, we include knowledge about the objects into the tomographic estimation schemes, in particular:

- locally homogeneous scattering density for each vegetation layer in spatial domain
- locally homogeneous tree heights, i.e., vegetation layers are parallel to profile of ground elevation
- typical heights of vegetation layers

This knowledge is formulated as a-priori probability density distributions and evaluated together with the result of model-based tomographic reconstruction in a Bayesian manner. The reconstruction quality will be investigated in view of different scene and sensor parameters, most importantly:

- number of image acquisitions
- image resolution
- baseline spread and baseline distribution
- tree heights
- number, height, and distribution of vegetation layers

The tomographic algorithms analyzed and tuned with the above simulations will be applied to the real data shown in Sect. 3. To thoroughly analyze the applicability of these algorithms, both man-made objects and forested areas should be contained in the scene. Results that are similar to pre-processed PSI stacks should be achieved at rigid man-made objects. For forested areas, on the other hand, the 3D distribution of volume scattering should be gained. In order to quantify the performance of SAR tomography, the 3D coordinates of single and multiple scatterers will be compared to a digital elevation model acquired by a full waveform laser scanner.

This comparison is in particular interesting, as both remote sensing techniques are able to capture the 3D reflectance function at or inside objects and therefore they are of special interest for analyzing forest environment. However, they differ fundamentally in the used electromagnetic bands (3cm-25cm for SAR and nm-µm for LIDAR), the sensor platform (usually satellites for tomography and aircrafts for LIDAR), as well as data processing and analyses methods: full waveform LIDAR [5] exploits the time-dependent intensity distribution [6] of one signal received by multiple echoes as shown by Jutzi & Stilla [7], while SAR tomography utilizes the complex-valued intensity records of one resolution cell sensed from different positions. It is thus of highest interest to further investigate the mutual support as well as the difference of both remote sensing technologies.

5. REFERENCES

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