Potential of Airborne Single-Pass Millimeterwave InSAR Data for Individual Tree Recognition

MICHAEL SCHMITT [1], AXEL BRÜCK [1], JOHANNES SCHÖNBERGER [1] & UWE STILLA [1]

Abstract: This paper shows the potential of airborne single-pass millimeterwave InSAR data for the recognition of individual trees. In addition to the very high available resolution in the decimeter range, the benefits of both single-pass interferometry as well as millimeterwave radar are discussed. Using knowledge of the side-looking imaging geometry, the representation of trees in airborne SAR data is modeled and compared to optical and LiDAR remote sensing data. Finally, two different concepts for automated single tree recognition are proposed in order to show the versatile potential of synthetic aperture radar interferometry for the required task.

Zusammenfassung: Dieser Aufsatz zeigt das Potential flugzeuggetragener Single-Pass Millimeterwellen InSAR-Daten für die Erkennung einzelner Bäume. Neben der sehr hohen verfügbaren Auflösung im Dezimeterbereich werden die Vorteile sowohl der Single-Pass-Interferometrie als auch des Millimeterwellen-Radar diskutiert. Unter Nutzung von Wissen über die seitwärts-blickende Abbildungsgeometrie wird die Erscheinung von Bäumen in flugzeuggetragenen SAR-Daten modelliert und mit optischen und LiDAR-Fernerkundungsdaten verglichen. Schließlich werden zwei unterschiedliche Ansätze zur automatisierten Einzelbaumerkennung vorgestellt um das vielseitige Potential von Radar-Interferometrie für die geforderte Aufgabe zu zeigen.

1 Motivation for Tree Recognition in InSAR Imagery

The automatic recognition of single trees in remote sensing data is an important topic for several application fields. The most important certainly is sustainable forest management: In many countries, single-tree related parameters are used as a basis for forest inventory, e.g. tree species, mean tree height or timber volume. To this date, most of these variables are collected manually by measurement of sample plots in cost- and time-intensive field surveys, although remote sensing-based methods have been investigated for some decades now (FAGAN & DEFRIES, 2009). Another potential application is the extraction of single trees in urban areas in order to generate information for city tree cadastres or to add tree layers to geoinformation systems and 3D city models (STRAUB & HEIPKE, 2001).
While most of the research concerning the utilization of synthetic aperture radar (SAR) for the remote sensing of trees and forests centers either around large-scale forest classification (PERKO et al., 2010), biomass and forest volume estimation using L band tomography (NEUMANN et al., 2010; MERCER et al., 2010), or canopy height model reconstruction using X band interferometry (IZZAWATI et al., 2006), most work on the individual tree level to this date is based

1) Photogrammetrie & Fernerkundung, Technische Universität München (TUM), Arcisstr. 21, 80333 München, http://www.pf.bv.tum.de

on optical imagery or LiDAR data, respectively. Some promising approaches in this field have been proposed: For example, WANG et al. (2004) employ a combination of edge and local maxima detection on the first principal component of airborne multi-spectral imagery in order to detect tree crowns and tree tops, whereas ERIKSON (2003) proposes a region growing method for the segmentation of tree crowns in aerial false color photographs, including a subsequent classification of the tree species. KOCH et al. (2006) transfer the local maxima approach to rasterized airborne LiDAR data. After possible tree tops are detected, the tree crowns are delineated using a pouring algorithm that makes use of model knowledge about tree shapes. Finally, one of the latest developments concerning single tree detection from remote sensing data is based on 3D segmentation of full waveform LiDAR measurements (REITBERGER et al., 2009).

In opposition to the rich literature on single tree recognition in optical and LiDAR remote sensing data, only little has been published on this topic based on the exploitation of synthetic aperture radar, which is certainly mostly due to the rather coarse resolutions of conventional SAR sensors available so far. One of the few exceptions is (HALLBERG et al., 2005), where VHF band SAR images acquired from multiple viewing angles are coregistered and combined to improve spatial and radiometric resolution. The enhanced imagery is then used to estimate the stem volume of individual trees from their related backscattering amplitudes.
The analysis of individual trees is, however, becoming more and more interesting with the new generation of SAR sensors that offer resolutions in the decimeter range. Therefore, this paper investigates the potential of single tree recognition in airborne single-pass millimeterwave InSAR data. As will be shown later, this sensor/data configuration is considered to be particularly suitable for the task.
In section 2 the data and the relevant sensor characteristics are introduced, in section 3 the geometrical imaging of trees in airborne SAR imagery is discussed. Section 4 shows a first concept for automatic tree recognition. Finally, section 5 discusses the findings of this study, before in section 6 conclusion and outlook are given.

2 Airborne Single-Pass Millimeterwave InSAR Data Characteristics

The main theme of this paper already implies that our work takes advantage of three core sensor properties: First of all, we intend to use interferometric SAR data, which enables the derivation of tree heights and therefore delivers an additional indicator that can be exploited for tree detection. Second, we use single-pass data, giving us the possibility to work with high-coherent InSAR observations, a pre-requesite that has not been available to the satellite community until the launch of TanDEM-X in June 2010 (KRIEGER et al., 2007). Third, we employ millimeterwave radar data in the Ka band. In opposition to the more common X band (wavelength: about 3 cm), millimeterwave data is known to penetrate the tree canopy even less (see Fig. 1), thus giving way to a more accurate height estimation.

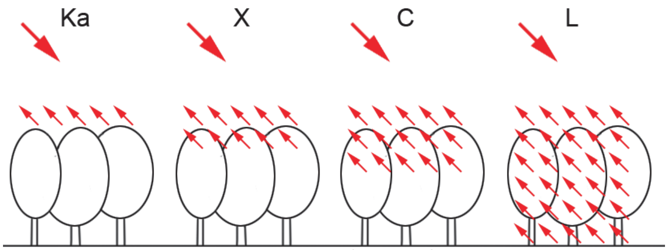

Fig. 1: Tree canopy penetration of common SAR wavelengths.

2.1 MEMPHIS SAR System

For the considerations in this paper, the German MEMPHIS (***M**illimeterwave* ***E**xperimental* ***M**ultifrequency* ***P**olarimetric* ***H**igh* *Resolution* ***I**nterferometric* ***S**ystem*) by the Fraunhofer Institute for High Frequency Physics and Radar Techniques is used as an exemplary sensor (SCHIMPF et al., 2002). Although it is able to be operated in different modes and configurations, we employ the basic airborne side-looking configuration with a carrier frequency of 35 GHz (Ka band), and a bandwidth of 900 MHz, leading to a slant range resolution of 16.5 cm. Since MEMPHIS is equipped with four receiving antennas, a number of single-pass interferograms with different baselines can be created. However, in this work, only the longest baseline (length: 27.5 cm, corresponding ambiguity height: 42 m) was used; the utilization of the remaining interferograms or a full multi-baseline configuration is part of ongoing research. An overview of the relevant sensor parameters is given in Table 1.

MEMPHIS sensor system	
Band	Ka band (35 GHz)
Wavelength	8.54 mm
Pixel spacing (slant range)	5.1 cm (azimuth) 16.7 cm (range)
Baseline used	27.5 cm
Ambiguity Height	42 m
Test scene “Alte Pinakothek”	
Flying altitude	768 m
Heading angle	340°
Depression angle	30°

Tab. 1: Sensor and test scene parameters

2.2 Test Scene

The available MEMPHIS test data were acquired on a campaign over Munich, Germany, in 2011. While the scene is centered at the main campus of Technische Universitaet Muenchen (TUM) close to the city center and therefore contains mostly dense building blocks, there are some interesting sub-scenes containing a number of trees: The one that is used in this paper is a small group of trees next to the “Alte Pinakothek”, a museum close to TUM main campus. The radar intensity in slant range geometry with approximately square pixels and an orthophoto of the scene are shown in Fig. 2. Although the visual impression of the trees is unexpectedly nice in the SAR image, in the following section we will show that due to the imaging geometry an interpretation is still non-trivial. In Fig. 3 ground photographs of the scene are displayed in order to facilitate a deeper understanding of the tree configuration.

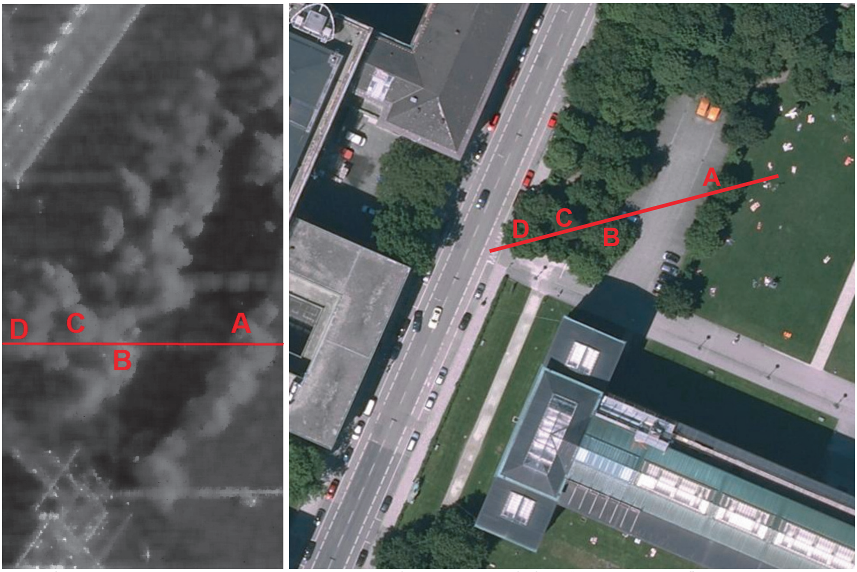

Fig. 2: SAR intensity image in slant range geometry (left), orthophoto of of the “Alte Pinakothek” test scene (right). The red line indicates a range profile corresponding to the radar’s viewing direction. A, B, C and D are trees appearing in this range line.

Fig. 3: Ground photographs showing the four trees (A,B,C,D) appearing in the range line indicated in Fig. 2

3 Modelling of the Representation of Trees in InSAR Images

While the pictorial appearance of trees has long been studied for optical remote sensing imagery and LiDAR data, only little is known about the SAR imaging characteristics on single tree level. The main difference to the conventional sensor types is certainly the side-looking imaging geometry leading to well-known effects like foreshortening, layover and shadowing: Layover generally occurs whenever the terrain slope (or any other object) is steeper than a line perpendicular to the radar line-of-sight defined by its depression angle. Surfaces that are less steep but elevated nonetheless, will not be represented in true size as well. Instead, they will be displayed compressed, while still containing the full backscattering energy. Surfaces facing away from the antenna finally will return no signal to the radar at all. Figure 4 shows a model for the line-of-sight depicted in Fig. 2.

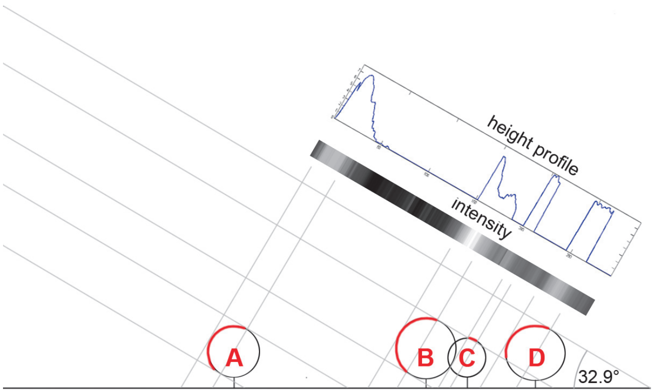

Fig. 4: Backscattering and corresponding height profile of the four trees (as reconstructed by interferometric phase-to-height conversion) for the range profile introduced in Fig. 2.

It can clearly be assessed that only the upper front parts of the trees are directly imaged by the SAR – as long as the respective tree is not affected by the shadowing effect of another tree. Here, tree C is depicted significantly smaller than the other trees due to the fact that the radar line-of-sight does not go through its center but only touches the outer part of its canopy. Therefore, tree C is mostly affected by the shadowing of tree B. Appearances like this naturally exacerbate any kind of automatic image analysis. The locations of the backscattering maxima determined by local maxima detection are shown in Fig. 5. It is obvious that the maximum backscattering energy for each tree appears oriented towards the sensor. Thus, local intensity maxima cannot be considered valid hypotheses for the center (trunk) position of the corresponding trees without further correction.

4 Preliminary Concepts for Automatic Tree Recognition

Considering the imaging peculiarities of the side-looking SAR geometry, we propose two different preliminary concepts for automated tree recognition. The first is meant to take place in the slant range plane, i.e. directly in the SAR image and in products that may be derived from exploitation in the sense of interferometry (e.g. coherence maps, interferograms, height maps).

Fig. 5: Local maxima (white boxes) detected in the SAR intensity image (left). These maxima are projected into an orthophoto (July 2009) overlayed with a LiDAR point cloud (September 2009) in order to show their real world position (right). The SAR viewing direction is indicated by the red arrows. The red circles indicate manually determined tree top positions. Note how all detected maxima are located towards the sensor.

The second is intended to make use of interferometric 3D reconstruction possibilities. Here, in a first step 3D point clouds are derived from the available interferograms, and afterwards trees are detected in the 3D data in the vein of LiDAR-based approaches.

4.1 Image-based Tree Recognition

A flowchart of the image-based concept is shown in Fig. 6. It is inspired by work on tree recognition from optical remote sensing data and centers around the detection of local maxima in the SAR intensity data. As proposed by (POPESCU & WYNNE, 2004), the search radius of the local maxima detection is derived by prior knowledge about the canopy height. In the InSAR case, this height information can easily be derived from the interferometric phase information if two (or more) coregistered single-pass acquisitions of the scene are available. Due to the fact that trees (and, in the case of urban areas, buildings) lead to shadow occlusions, leaving just noisy phase measurements, the according coherence map can be used to eliminate shadow pixels from the interferogram. After the local maxima are found, they serve as preliminary tree hypotheses, and patches of a certain radius are extracted around them. Within each of these patches, edge detection is applied in order to extract the contour caused by strong reflections oriented towards the sensor. Using this contour as input for a circle fitting procedure, finally the tree crown is delineated, whose center is considered to be the true tree position. Using the height previously generated from the interferogram, the tree can be reconstructed with respect to its georeferenced position in a world coordinate system.

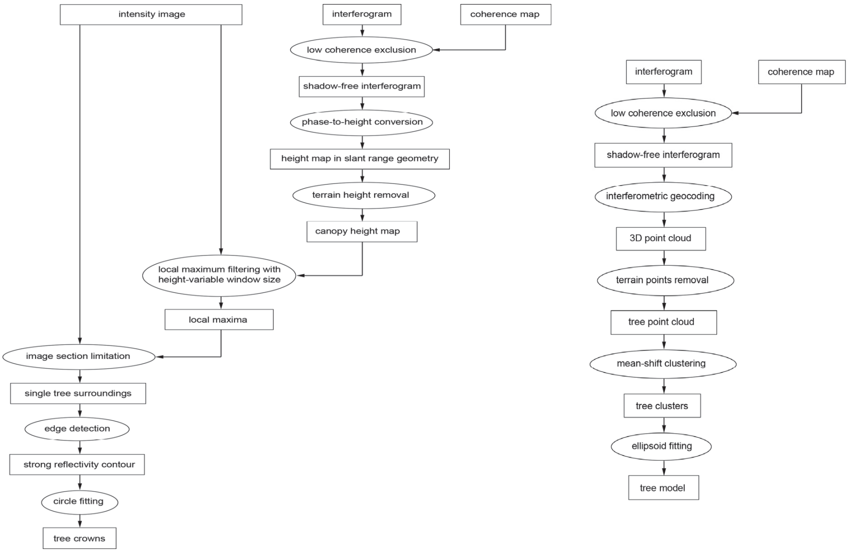

Fig.6: Workflows of the proposed tree recognition concepts. Left: Image-based approach. Right: 3D-based approach.

4.2 3D-based Tree Recognition

The flowchart of the 3D-based concept is also shown in Fig. 6. Here, the (interferometric) SAR data is used to reconstruct georeferenced 3D points, which are then used as input information for tree recognition. Therefore, the general nature of this concept is inspired by the related works of the LiDAR community (GUPTA, 2010). In a first step, the pre-processed InSAR data is geocoded using the interferometric range-Doppler equations, resulting in a point cloud that corresponds to the SAR image resolution concerning point density. For the available MEMPHIS data, this is up to about 100 points per m², highly depending on the terrain slope due to foreshortening and shadowing. An exemplary conventional InSAR point cloud is compared to a LiDAR point cloud in Fig. 7. It can easily be seen that both point clouds differ in their structure, which is due to the side-looking nature of SAR systems. The most important difference is caused by the layover effect that can nicely be seen in form of points shifted towards the sensor. But also the radar shadow has a significant impact causing comparably large holes in the point cloud, which could, however, easily be filled using multi-aspect InSAR methods (SCHMITT & STILLA, 2011). Nevertheless, the overall height trend corresponds to what we see in the LiDAR data. In order to exploit the dense InSAR point cloud, we propose the application of a clustering algorithm, e.g. mean-shift clustering (COMANICIU & MEER, 2002) leading to clusters of 3D points grouped to single trees. The resulting clusters can then be used as input for the parameterization of the tree: For example, height and diameter can be corrected with respect to the known imaging geometry, such that e.g. the mathematical model of a rotation ellipsoid can be fitted to the cluster to deduce a simple tree model.

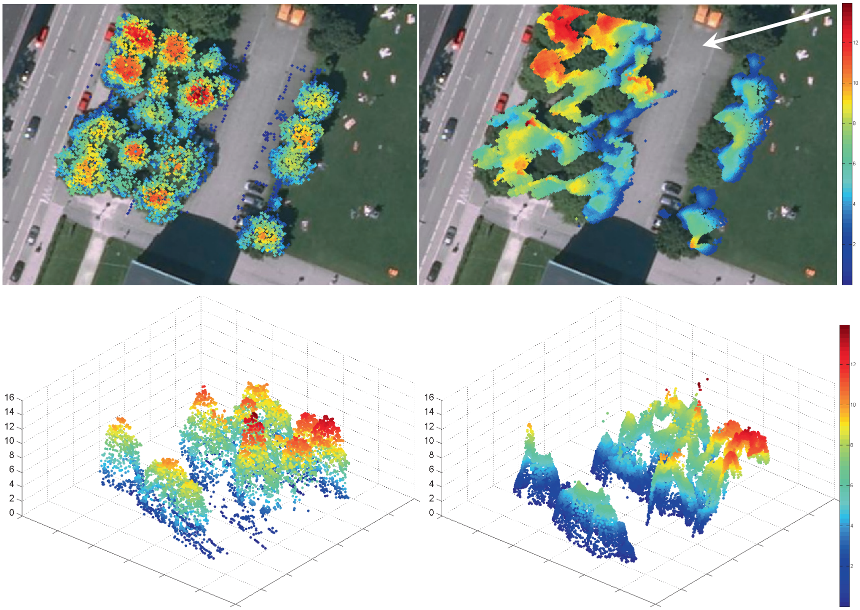

Fig. 7: Top row: Two-dimensional representation of LiDAR point cloud (left) and InSAR point cloud (right). Note how many parts of the InSAR tree heights are affected by layover. The white arrow shows the SAR viewing direction. Bottom row: Three-dimensional view of LiDAR point cloud (left) and InSAR point cloud (right), approximately from the SAR perspective.

5 Discussion

Due to the imaging characteristics of optical remote sensing systems, which are quite familiar to the human visual system or the convenience of high resolution point clouds as they are created by LiDAR sensors, manual, semi-automatic and automatic tree recognition is obviously fancied using data of this kind of sensors. There are, however, a number of arguments that speak in favour of the utilization of synthetic aperture radar for this task as well. First of all, the night-and-day and relative all-weather capability of SAR has to be mentioned. Although forest inventory tasks are usually not as time-critical as disaster response situations, time is still an expense factor. Therefore, the possibility to carry out flight campaigns without respect to the actual weather or daylight conditions provides a noteworthy advantage, especially if we consider that most forested areas see relatively high cloud coverage. Furthermore, SAR has been described to have a good cost-performance ratio since large swaths can be imaged with one single track.

In addition to that, there is another advantage more from the methodological point of view: Single-pass InSAR data provides both radiometric as well as height information in form of intensity images and interferograms. Both kinds of data are precisely coregistered by their very nature, which enables a joint exploitation without any error-prone pre-processing steps and without the need to buy additional external data. On the other hand, it has to be admitted that the side-looking SAR imaging geometry introduces challenges for both manual and automated image analysis that seem more severe than in conventional remote sensing data. Especially Figs. 5 and 7 nicely illustrate the effects caused by foreshortening (intensity maxima shifted towards sensor), layover (tree heights shifted towards sensor) and shadowing (missing data behind trees). In spite of these drawbacks, a further investigation of forest remote sensing and tree recognition based on single-pass InSAR data seems promising.

6 Conclusion & Outlook

In this paper we have discussed the potential of airborne single-pass millimeterwave InSAR data for the recognition of single trees. The considerations were carried out using experimental data in an urban environment and can readily be extended to forest scenarios. It has been shown that airborne InSAR data with range and azimuth resolutions in the decimeter range can potentially be used for the analysis of wooded areas on a single tree level. Furthermore, the usefulness of single-pass data as well as millimeterwave frequencies has been shown. However, it has to be noted that the side-looking imaging geometry inherent to synthetic aperture radar sensors leads to challenging imaging effects that have to be considered when the tree detection process is modelled.

Finally, two different concepts for automated recognition of individual trees have been introduced: One in the SAR image space exploiting radiometric information as well as height maps in slant range geometry derived from interferometric phase information; the other one in object space exploiting 3D point cloud data reconstructed by interferometric geocoding. The investigation of their applicability, especially with respect to established methods from the field of optical and LiDAR remote sensing, will be in the focus of future research.

7 Acknowledgment

The authors would like to express their thanks to Stephan Stanko and Thorsten Brehm of Fraunhofer FHR as well as Erich Meier and Christophe Magnard of RSL Zurich for providing the MEMPHIS test data. We would also like to thank Marcus Hebel of Fraunhofer IOSB for providing the reference LiDAR data and LVG Muenchen for the orthophoto.

8 Literaturverzeichnis

COMANICIU, D. & MEER, P., 2002: Mean Shift: A robust approach toward feature space analysis. IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 24, No. 5, pp. 603-619

ERIKSON, M., 2003: Segmentation of individual tree crowns in colour aerial photographs using region growing supported by fuzzy rules. Canadian Journal of Forest Research, Vol. 33, No. 8, pp. 1557-1563

FAGAN, M. & DEFRIES, R., 2009: Measurment and monitoring of the world's forests. A review and summary of remote sensing technical capability 2009-2015. RFF Report

GUPTA, S., 2010: Single tree detection and modeling using airborne laser scanner data. PhD Thesis, Faculty of Forest and Environmental Sciences, Albert-Ludwigs-Universität Freiburg im Breisgau

HALLBERG, B.; SMITH-JONFORSEN, G. & L.M.H. ULANDER, 2005: Measurements on individual trees using multiple VHF SAR images. IEEE Transactions on Geoscience and Remote Sensing, Vol. 43, No. 10, pp. 2261-2269

IZZAWATI; WALLINGTON, E.D. & WOODHOUSE, I.H., 2006: Forest height retrieval from commercial X-band SAR products. IEEE Transactions on Geoscience and Remote Sensing, Vol. 44, No. 4, pp. 863-870

KOCH, B.; HEYDER, U. & WEINACKER, H., 2006: Detection of individual tree crowns in airborne LiDAR data. Photogrammetric Engineering & Remote Sensing, Vol. 72, No. 4, pp. 357-363

KRIEGER, G.; MOREIRA, A.; FIEDLER, H.; HAJNSEK, I.; WERNER, M.; YOUNIS, M. & ZINK, M., 2007: TanDEM-X: A Satellite Formation for High-Resolution SAR Interferometry. IEEE Transactions on Geoscience and Remote Sensing, Vol. 45, No. 11, pp. 3317-3340

MERCER, B.; ZHANG, Q.; SCHWÄBISCH, M. & DENBINA, M., 2010: Estimation of forest biomass from an airborne single-pass L-band Pol-InSAR system. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. 38, No. 1, on CD

NEUMANN, M.; FERRO-FAMIL, L. & REIGBER, A., 2010: Estimation of forest structure, ground, and canopy layer characteristics from multi-baseline polarimetric interferometric SAR data. IEEE Transactions on Geoscience and Remote Sensing, Vol. 48, No. 3, pp. 1086-1104

PERKO, R.; RAGGAM, H.; GUTJAHR, K. & SCHARDT, M., 2010: The capabilities of TerraSAR-X imagery for retrieval of forest parameters. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. 38, No. 7B, pp. 452-456

POPESCU, S.C. & WYNNE, R.H., 2004: Seeing the trees in the forest: Using LiDAR and multispectral data fusion with local filtering and variable window size for estimating tree height. Photogrammetric Engineering & Remote Sensing, Vol. 70, No. 5, pp. 589-604

REITBERGER, J.; SCHNÖRR, C.; KRZYSTEK, P. & STILLA, U., 2009: 3D segmentation of single trees exploiting full waveform LiDAR data. ISPRS Journal of Photogrammetry and Remote Sensing, Vol. 64, No. 6, pp. 561-574

SCHIMPF, H.; ESSEN, H.; BOEHMSDORFF, S. & BREHM, T., 2002: MEMPHIS – a fully polarimetric experimental radar. Proceedings of IEEE International Geoscience and Remote Sensing Symposium, pp. 1714-1716

SCHMITT, M. & STILLA, U., 2011: Fusion of airborne multi-aspect InSAR data by simultaneous backward geocoding. Proceedings of Joint Urban Remote Sensing Event, pp. 53-56

STRAUB, B.-M. & HEIPKE, C., 2001: Automatic extraction of trees for 3D-city models from images and height data. In: BALTSAVIAS, E.P.; GRUEN, A. & VAN GOOL, L. (Eds.): Automatic Extraction of Man-Made Objects from Aerial and Space Images (III), pp. 267-277

WANG, L.; GONG, P. & BIGING, G.S., 2004: Individual tree-crown delineation and treetop detection in high-spatial-resolution aerial imagery. Photogrammetric Engineering & Remote Sensing, Vol. 70, No. 3, pp. 351-357

Publikationen der Deutschen Gesellschaft für Photogrammetrie, Fernerkundung und Geoinformation e.V.

DGPF

Band 22 **2013**

Vorträge

33. Wissenschaftlich-Technische Jahrestagung der DGPF

27. Februar – 1. März 2013
in Freiburg i. B.

Dreiländertagung D - A - CH

ISSN 0942-2870

Eckhardt Seyfert, Hrsg.