Representation of stationary vehicles in ultra-high resolution SAR and turntable ISAR images

Andreas R. Brenner[1], Helmut Essen[1], Uwe Stilla[2]

[1] Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR, 53343 Wachtberg, Germany
[2] Photogrammetry and Remote Sensing, Technische Universitaet Muenchen, 80290 Muenchen, Germany

Abstract

The SAR/GMTI sensor PAMIR of Fraunhofer FHR supports in its newest upgrade a bandwidth of 3.6 GHz enabling a resolution of about 4 cm. This capability allows detailed image analysis in urban areas, e.g. the detection and classification of stationary vehicles. To this end SAR images of stationary vehicles in different resolution scales has been analysed and evaluated in comparison to turntable ISAR images.

Introduction

The increasing traffic volume over the last decades poses high challenges on today's traffic research and planning. Current road systems are equipped with a suite of sensors for monitoring traffic status: induction loops, overhead radar sensors, video systems are the most prominent examples. They all deliver accurate, reliable, timely, yet merely point-wise measurements. Airborne and spaceborne imaging systems, on the other hand, provide synoptic views of complex traffic situations and the associated context [1]. These data are complementary to the ones of road sensors and can either be used in research for improving traffic models [2] or as information source for traffic related statistics [3].

In the last years approaches for detection of moving and stationary vehicles using data from different sensors and platforms have been developed, like optical satellite imagery [4], aerial image sequences [5], aerial thermal videos [6] or point clouds from laser scanners [7]. While vehicle detection and velocity estimation from SAR using approaches for Moving Target Identification (MTI) based on along track interferometry has been extensively investigated in the past (e.g. [8], [9]) little attention has been paid to detection of stationary vehicles from very high resolution airborne SAR imagery. Nowadays leading edge SAR sensors allow a mapping of vehicles in the decimetre and sub-decimetre domain. The fact that a vehicle appears not just as a blob or a spot in the image, but rather showing a certain structure should enable applying structure based approaches for detection of single vehicles or groups of vehicles.

In this paper, the initial situation on the part of the SAR imagery will be exemplarily illuminated. Representations of stationary vehicles acquired by airborne SAR within the resolution range from roughly 50 cm to 5 cm will be given. In comparison to the airborne case ground based turntable ISAR results are presented as well.

SAR Imaging of Stationary Vehicles

Based on switchable true-time delays the SAR/GMTI sensor PAMIR of Fraunhofer FHR allows broadband electronic antenna steering over an interval of up to 90 degrees [10], which is mandatory for an ultra-high two-dimensional resolution in X-band SAR imaging. With its last upgrade (Table 1), PAMIR supports now an instantaneous bandwidth of 3.6 GHz enabling an outstanding image resolution smaller than 4 cm times 4 cm [11], [12].

This capability opens new perspectives in SAR applications and SAR image interpretation, especially in structural image analysis applied to urban areas. As one out of various tasks the detection and classification of stationary vehicles in different resolution scales is an actual research topic. Dependent on the available resolution not only the pure existence of a vehicle can be proven, moreover, its orientation or even the differentiation of vehicle classes comes within reach.

In Fig. 1 a large parking area at a car terminal in Bremerhaven is shown. Here many vehicles of similar type are parked very densely in a door-to-door and bumper-to-bumper manner. The intrinsic resolution of the image is 13 cm times 13 cm. In Fig. 2 an optical photo of this area acquired at another time is given.

The resolution-dependent representation of stationary vehicles can be evaluated by means of the SAR images of a small parking lot in Fig. 3. To the left of the figure a SAR image acquired by a survey mode is shown. The resolution amounts to 62 cm times 34 cm. The vehicles offer somewhat more structure than a pure blob, but appear quite diffuse and interconnected. The situation changes fundamentally

Fig. 1. SAR image of a car terminal in Bremerhaven with rail tracks, freight wagons and a fully populated parking lot.

Fig. 2. Optical image of the car terminal shown in Fig. 1 (non-coincident acquisitions). © Google Maps

by using a high resolution mode: on the right-hand side a resolution of 15 cm times 7 cm allows a distinct detection of single vehicles. It should be mentioned that with finer resolution the detection of single vehicles is facilitated but the detector has now to deal with the fine structure appearance of a single vehicle itself as well. Further, due to the limited aspect angle interval during radar acquisition and the mostly specular reflections on the vehicles surface, the appearance of vehicles in SAR images is strongly aspect angle dependent leading to a broad variance in the vehicle representation.

Finally, in Fig. 4 the result of an ultra-high resolution sliding spotlight mode along a linear flight track is shown. Five passenger cars were illuminated over an aspect angle interval of 85° using the maximum bandwidth of 3.6 GHz. Due to the large aspect angle interval, range and depression angle varies strongly during the data acquisition. The severely curved set in Cartesian k-space is therefore implicitly weighted. The achieved ground resolution is determined to 4 cm times 2 cm and the mean depression angle amounts to 33°. The representation of the respective vehicles stretches out over some 10^4 resolution cells and reveals a very detailed fine structure. Orientation of the vehicles and product typical design features can clearly be determined. Further, wing mirrors, sliding roofs and inside the vehicles front seats and head restraints can be recognised as well - the way for a coarse classification seems to be paved. In Fig. 5 a corresponding photograph of the scene is given. Attention should be paid to the image orientations: due to the top-to-bottom range direction in the SAR image, the leftmost vehicle in the photograph is the rightmost one in the SAR image, and so on.

Carrier	Transall C-160
Centre frequency	9 GHz (X-band)
Bandwidth	3.6 GHz
Resolution	< 4 cm x 4 cm
Range	up to 100 km
Channels	5 parallel receive channels
Main antenna	Active phased array, electronically steerable 256 T/R modules
Transmit power	up to 1280 W peak
Azimuth scan	+- 45 deg
Polarisation	VV
Basic operational modes	Squinted stripmap SAR Spotlight and sliding mode SAR Interferometric SAR Scan MTI, Spotlight MTI ISAR

Table 1: System specification of PAMIR (2010)

Comparison with Turntable ISAR

The development of radar based detection and classification procedures for vehicles can benefit significantly from a detailed knowledge of their scattering centre distribution in dependence on target

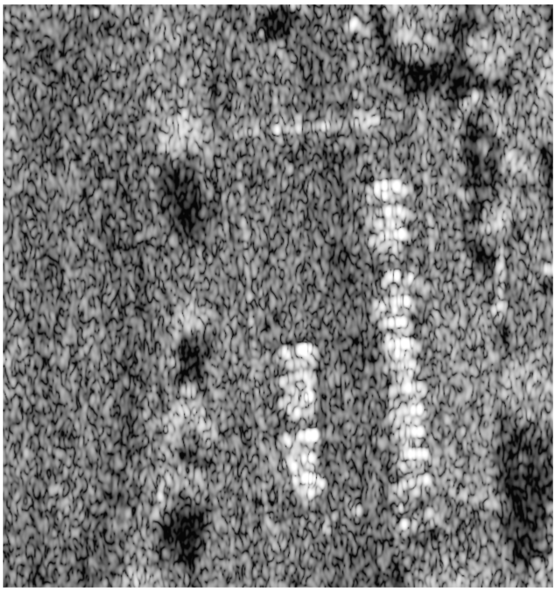
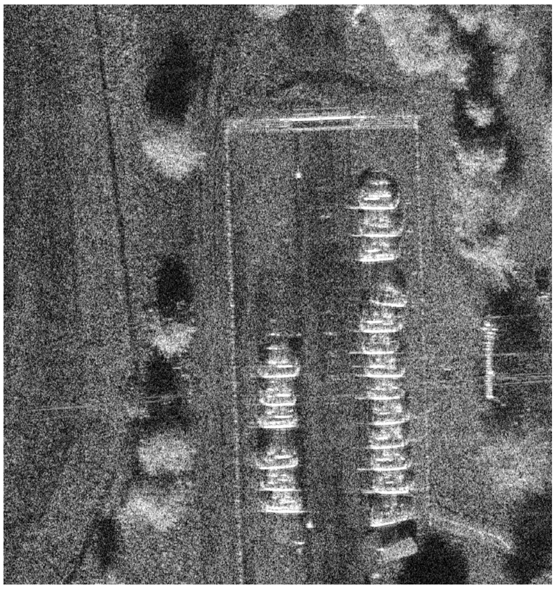

Fig. 3. Vehicles on a small parking lot. To the left, a survey mode with a resolution of 62 cm times 34 cm and to the right a high resolution mode with a resolution of 15 cm times 7 cm was applied (range times azimuth). The scene was illuminated from opposite directions.

azimuth and elevation angle. One method, which is capable of delivering two dimensional scattering centre distributions is the inverse synthetic aperture approach (ISAR), using tower-turntable geometry.

For comparison of stationary vehicles in airborne SAR images with ISAR images of the same vehicles such turntable measurements have been conducted. The experimental radar COBRA was employed, which is capable of operating at different bands with an FMCW waveform [13],[14]. For the measurements presented here, the X-band was used. The available bandwidth fits quite well to the one of PAMIR, allowing to give a thorough comparison of ground based and airborne measurements. The aspect angle and the angular interval over which data were sampled for one image can be chosen accordingly.

For applications, where the overall characteristics of a target related to its scattering centre distribution have to be known, accumulated scattering distributions can be derived, which characterize any resolved position on the target by the maximum RCS measured under any aspect angle within the total interval of 360°. For the comparison with SAR signatures, where the vehicles are only appearing over a certain aspect angle range, related images can be generated.

As an example, the Mercedes-Benz used in the SAR scene (second from right in the SAR image) was utilised for a comparative turntable measurement. In Fig. 6 the ISAR image accumulated over 75° is shown. The centre frequency was 10 GHz and the bandwidth 4 GHz. Due to security restrictions the effective depression angle was limited to 13°. Despite the different realised depression angles there is a substantial matching between the SAR and the ISAR image.

Under the advantageous conditions of turntable experiments the electromagnetic behaviour of vehicles can be easily measured and corresponding SAR representations can be predicted. COBRA operates at different wavelengths with large bandwidths and all polarisations [14]. RCS simulation in case of available CAD models can support this process as well.

Conclusion

Ultra-high resolution airborne SAR images will give a considerable contribution to urban analysis and especially to stationary vehicle detection and classification. Interesting applications in the field of urban traffic models and planning, traffic related statistics and management of public traffic areas seem to be feasible.

References

[1] U. Stilla, E. Michaelsen, U. Soergel, S. Hinz, J. Ender, "Airborne monitoring of vehicle activity in urban areas," *Int. Arch. Photogram. Rem. Sens. Spatial. Inform. Sci.*, vol. 35, Part B3, pp. 973–979, 2004.

[2] S. Hinz, U. Stilla, "Car detection in aerial thermal images by local and global evidence accumulation," *Pattern Recogn. Lett.*, vol. 27, no. 4, pp. 308–315, 2006.

[3] M. McCord, P. Goel, Z. Jiang, B. Coifman, Y. Yang, C. J. Merry, "Improving AADT and VDT estimation with high-resolution satellite imagery," in *Proc. Pecora 15/Land Satellite Information IV Symp.*, Denver, Colorado, USA, 2002, 9 pages (on CDROM).

[4] J. Leitloff, S. Hinz, U. Stilla. "Vehicle detection in very high resolution satellite images of city areas." *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 7, pp. 2795-2806, 2010.

[5] D. Lenhart, S. Hinz, J. Leitloff, U. Stilla, "Automatic traffic monitoring based on aerial image sequences," *Pattern Recognit. Image Anal.*, vol. 18, no. 3, pp. 400–405, 2008.

[6] M. Kirchhof, U. Stilla, "Detection of moving objects in airborne thermal videos," *ISPRS J. Photogramm. Remote Sens.*, vol. 61, no. 3/4, pp. 187–196, 2006.

[7] W. Yao, U. Stilla. "Comparison of two methods for vehicle extraction from airborne LiDAR data toward motion analysis", *IEEE Geosci. Remote Sens. Letters*, vol. 8, no. 4, 607-611, 2011.

[8] J. Ender, "Space-time processing for multichannel synthetic

aperture radar," *Electron. Commun. Eng. J.*, vol. 11, no. 1, pp. 29–38, 1999.

[9] D. Cerutti-Maori, J. Klare, A. R. Brenner, J. Ender, "Wide-area traffic monitoring with the SAR/GMTI system PAMIR," *IEEE Trans. Geosci. Remote Sens.*, vol. 46, no. 10, pp. 3019–3030, 2008.

[10] A. R. Brenner, J. H. G. Ender, „Demonstration of advanced reconnaissance techniques with the airborne SAR/GMTI sensor PAMIR", *IEE Proceedings - Radar, Sonar, Navigation*, vol. 153, no. 2, pp. 152-162, 2006.

[11] A. R. Brenner, L. Roessing, "Radar imaging of urban areas by means of very high resolution SAR and interferometric SAR", *IEEE Trans. Geosci. Remote Sens.*, vol. 46, issue 10, part 1, pp. 2971-2982, 2008.

[12] A. R. Brenner, "Proof of concept for airborne SAR imaging with 5 cm resolution in X-band", *Proc. EUSAR 2010*, pp. 615-618, 2010.

[13] H. Essen, M. Haegelen, A. Wahlen, R. Sommer, W. Johannes, T. Brehm, S. Stanko, "High resolution scattering centre distributions at millimetre wave frequencies derived by broad band ISAR", *Second European Conference on Antennas and Propagation (EuCAP 2007)*, 2007.

[14] H. Essen, A. Wahlen, J. Wilcke, G. Biegel, W. Johannes, R. Sommer, "High resolution tower-turntable ISAR with the millimetre wave radar COBRA (35/94/220 GHz)", *Proc. EUSAR 2008*, vol. 3, pp. 145-148, 2008.

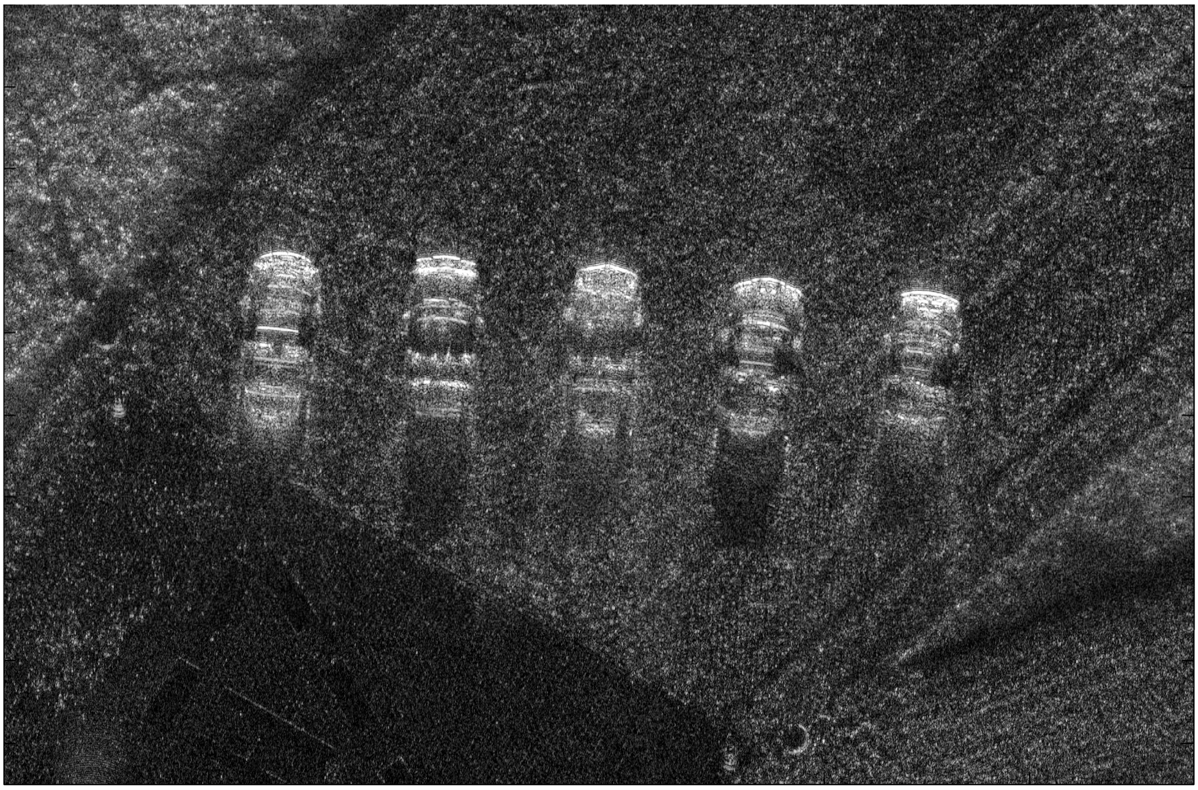

Fig. 4. SAR image of five passenger cars based on an ultra-high resolution sliding spotlight mode of PAMIR.
The resolution was estimated to 4 cm times 2 cm (range times azimuth).

Fig. 5. Photo of the passenger cars displayed in Fig. 4.

Fig. 6. Photo and turntable ISAR image of a Mercedes-Benz (accumulated over 75°, centre frequency 10 GHz, bandwidth 4 GHz).