Fast Post-Doppler STAP with Road Map for Traffic Monitoring

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Abstract. Synthetic aperture radar (SAR) is an efficient solution for road traffic monitoring due to its high spatial resolution and independence from daylight and weather conditions. Several ground moving target indication (GMTI) algorithms have been developed, whereas their robustness is often achieved with high costs, hardware complexity and computational burden. This paper presents a fast GMTI processor that blends the powerful post-Doppler space-time adaptive processing (PD STAP) with the OpenStreetMap (OSM). The algorithm has great potential for real-time processing, decreased hardware complexity and low costs compared to state-of-the-art systems. It is tested using 4-channel data acquired with DLR's airborne F-SAR.

1 Introduction

Road traffic monitoring is nowadays a trending topic due to the worldwide increase of road users. Safe and efficient roadway operations require accurate traffic data, whereas detailed traffic information is often available only in the major highways. SAR offers unique image capability for road traffic monitoring by providing high-resolution two-dimensional images (i.e., reflectivity maps) independent from daylight, cloud coverage and weather conditions [1-3]. Especially in case of large scale events and natural disasters (i.e., when mobile internet is unavailable and phone communication is impossible), road traffic monitoring with real-time information ensures the safety of the road users and can even save lives.

State-of-the-art GMTI algorithms are available in the literature using a priori knowledge information [4-6], whereas they often require high hardware complexity and high computational effort. Thus, especially when real-time processing is desired, the use of such algorithms would further increase the complexity of STAP, which is a very complex algorithm itself.

This paper presents a fast PD STAP processor that uses a priori road map information from the OSM fused with a digital elevation model (DEM) in order to recognize and to reject false detections, and moreover, to assign the detected cars to the correct roads. Besides, accurate estimates of the cars' velocities and moving directions are obtained. Unlike conventional PD STAP algorithms (that process the complete radar data), the proposed algorithm uses the OSM road map for selecting and processing only the relevant data around the roads, thus speeding up the processing time significantly.

2 Proposed Processor

The simplified flowchart of the proposed processor is shown in Fig. 1a. The radar multi-channel range compressed (RC) data are received and calibrated. The *Calibration* step corrects the along-track interferometry (ATI) phase and amplitude offsets of the channels. The range-dependent Doppler centroid is also corrected (commonly known as “J-Hook” [7]). The *Training Data Selection* step collects homogeneous and moving targets-free data for the clutter covariance matrix (CCM) estimation. The quality of the training data impacts the PD STAP performance, since the CCM is used for clutter cancellation (strategies for training data selection are presented in [8-9]). The *Data Selection* step collects only the relevant azimuth samples around the OSM road axis (cf. Fig. 1b), feeding the *PD STAP Processor*. The PD STAP is well-known [10-14] and is applied for cancelling the clutter and for estimating the slant-range, the direction-of-arrival (DOA) angle and the Doppler frequency of the target. These parameters are required for estimating the position and the slant-range velocity of the target [15].

The *Coordinate Transformation* step converts the radar coordinates (azimuth-range) of the detections to the Universal Transverse Mercator (UTM) coordinates system, used by the *Post-Detection Module*. This module fuses two freely available data bases: the road map from the OSM [16] and the DEM from the Shuttle Radar Topography Mission (SRTM) [17]. The DEM is necessary, since the OSM does not provide any height information. The decision whether the PD STAP detections are true or not is carried out by the *Error Models and Decision* step. In this case, two positioning error models are applied: 1) for the PD STAP detections and 2) for the OSM road points [18]. Thus, true detections are relocated to their corresponding OSM road axes and false detections are discarded. Finally, the data are formatted (e.g., Keyhole Markup Language (KML) files are generated for visualization in Google Earth) and distributed (e.g., to the traffic management center).

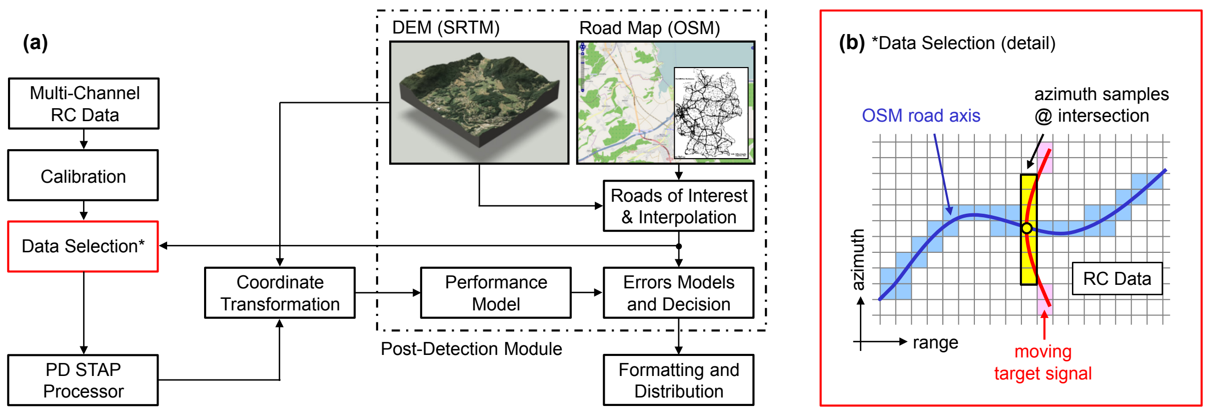

Figure 1: Principle of the proposed processor: (a) simplified flowchart and (b) detail of the *Data Selection* step using a road map.

3 Experimental Results

The proposed processor was tested using real 4-channel X-band radar data acquired with the DLR’s airborne F-SAR. The flight campaign was conducted over the Allgäu airport in Memmingen using five controlled cars, as shown in the optical image in Fig. 2a. The velocities of the cars and the radar parameters are given in [19-20]. For each OSM road point, 128 azimuth samples were taken for PD STAP processing. Thus, Fig. 2b shows the data selected around the runway (945 x 128 road-Doppler samples) before clutter cancellation (BCC), where the clutter bandwidth can be seen centered at zero-Doppler. Figure 2c shows the same data after clutter cancellation (ACC). Note that the region outside the clutter bandwidth cannot be suppressed due to the noise. Figure 2d shows the binary map of the detected targets, where the signals from all the cars and from the corner reflector (CR) can be noticed. Figure 2e shows the final GMTI results after relocating the targets to the OSM road axis. In this figure, the triangles point to the heading angles of the cars and the colors are related to their absolute ground range velocities. The estimated positions and velocities from cars 1-4 agreed with the measurements shown in [19-20]. Car 5 was discarded as false detection in the *Error Models and Decision* step (cf. Fig. 1a), since it moved "off-road".

The experimental data were also processed by our conventional PD STAP [21] that processed the full image. In this case, the conventional processor detected all the cars, whereas the processing time was 37 times worse than the proposed processor.

In a last experiment, the proposed processor was tested using another data take that included a section of the highway A7 with real traffic. Figure 2f shows the final GMTI results, where it can be seen that the traffic towards Ulm was more intense than towards Memmingen. Although no ground truth was available, the estimated velocities of the cars were reasonable.

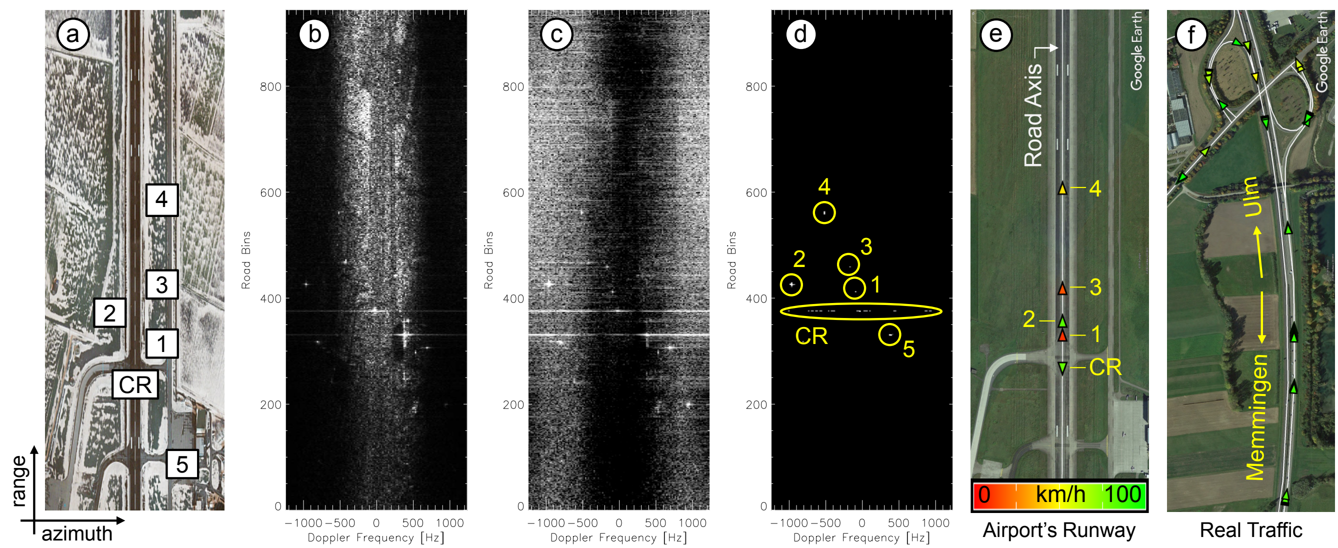

Figure 2: Results from real multi-channel radar data: (a) optical image of the airport's runway, (b) road-Doppler image (BCC), (c) road-Doppler image (ACC), (d) binary detection map (cars numbered from 1-5), (e) GMTI results from airport's runway and (f) GMTI results from real-traffic scenario in a section of the highway A7 (with several vehicles of opportunity).

4 Conclusions

The experimental results showed the robustness of our fast PD STAP processor for traffic monitoring. The processor detected all the controlled cars in the airport's runway with very good position and velocity accuracy, and rejected most of the false detections using a priori road map information and the error models. In this case, the proposed PD STAP processor was 37 times faster than the conventional one (without road map information). The GMTI results obtained from a real-traffic scenario showed that the cars were detected several times (so that a tracker can be applied for a further refinement) and their estimated velocities were reasonable. Thus, the power of our novel a priori knowledge-based processor was confirmed.

References

[1] A. Moreira, et al.: A tutorial on synthetic aperture radar, IEEE Geosci. Remote Sens. Mag., vol. 1, no. 1, pp. 6-43, 2013.

[2] K. Tomiyasu: Tutorial review of synthetic-aperture radar (SAR) with applications to imaging of the ocean surface, Proc. IEEE, vol. 66, no. 5, pp. 563-583, May 1978.

[3] J. C. Curlander and R. N. McDonough: Synthetic aperture radar: systems and signal processing, New York: Wiley, 1991.

[4] W. L. Melvin and G. A. Showman: An approach to knowledge-aided covariance estimation, IEEE Trans. AES, vol. 42, no. 3, pp. 1021–1042, Jul. 2006.

[5] J. H. Bang, W. L. Melvin and G. A. Showman: Model-Based Clutter Cancellation Based on Enhanced Knowledge-Aided Parametric Covariance Estimation, IEEE Trans. AES, vol. 51, no. 1, pp. 154–166, Jan. 2015.

[6] S. Gelli, et al: Effectiveness of Knowledge-Based STAP in Ground Targets Detection with Real Dataset, Proc. IET Radar, Oct. 2017.

[7] T. F. Ayoub, et al: Reduced-rank STAP for high PRF radar, IEEE Trans. AES, vol. 35, no. 3, pp. 953-962, July 1999.

[8] A. B. C. da Silva and S. V. Baumgartner: Training Data Selection and Update Strategies for Airborne Post-Doppler STAP, IEEE Trans. Geosci. Remote Sens. (submitted).

[9] A. B. C. da Silva and S. V. Baumgartner: Training Data Selection and Update for Airborne Post-Doppler STAP, Proc. EUSAR, Aachen, Germany, Jun. 2018 (accepted).

[10] W. L. Melvin: A STAP overview, IEEE AES Magazine, vol. 19, no. 1, pp. 19-35, Jan. 2004.

[11] R. Klemm: Space-time Adaptive Processing: Principles and Applications, London, UK: Inst. Elect. Eng., 1998.

[12] J. Ward: Space-Time Adaptive Processing for Airborne Radar, Lincoln Laboratory, MIT, TR-1015, 1994.

[13] J. H. G. Ender, C. H. Gierull and D. Cerutti-Maori: Improved space-based moving target indication via alternate transmission and receiver switching, IEEE Trans. Geosci. Remote Sens., vol. 46, no. 12, pp. 3960-3974, 2008.

[14] J. H. G. Ender: Space-time processing for multichannel synthetic aperture radar, Electron. Commun. Eng., 11, 1999.

[15] A. B. C. da Silva and S. V. Baumgartner: A priori knowledge-based STAP for traffic monitoring applications: first results, Proc. EUSAR, Hamburg, Germany, Jun. 2016.

[16] OpenStreetMap-The Free Wiki World Map, Apr. 2018. Available under: http://www.openstreetmap.org

[17] Shuttle Radar Topography Mission, Apr. 2018. Available under: https://www2.jpl.nasa.gov/srtm

[18] A. B. C. da Silva and S. V. Baumgartner: STAP moving target position estimation accuracy improvement and false detection recognition using a priori road information, Proc. IRS, Prague, Czech Republic, 2017.

[19] S. V. Baumgartner, et al: Digital beamforming and traffic monitoring using the new FSAR system of DLR, in Proc. IRS, Sep. 2007.

[20] A. Reigber, et al: Current status of DLRs new F-SAR sensor, Proc. EUSAR, Germany, 2010.

[21] A. B. C. da Silva and S. V. Baumgartner: Novel post-Doppler STAP with a priori knowledge in-formation for traffic monitoring applications: basic idea and first results, Advances in Radio Science, vol. 15, pp.77-82, 2017.