A Priori Knowledge-Based STAP for Traffic Monitoring Applications: First Results

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Abstract

This paper presents a novel a priori knowledge-based algorithm for traffic monitoring applications using the well-known post-Doppler space-time adaptive processing (PD STAP). The algorithm includes a road network obtained from the OpenStreetMap (OSM) database fused with a digital elevation model (DEM) to recognize and to reject false detections, and moreover, to reposition the vehicles detected in the vicinity of roads. The algorithm was verified using real data acquired by the DLR's airborne F-SAR. The first experimental results are discussed and compared with the results obtained by the conventional PD STAP without the benefits of a priori knowledge.

1 Introduction

Airborne monitoring of non-cooperative civilian road traffic is of great interest when the traffic information is required on a non-regular basis, as in the case of major events or disasters. Unlike military applications, where off-road targets also need to be detected, civilian applications require only the available road infrastructure on ground. Hence, since freely available road databases contain even small forest roads, e.g., the OSM database [1], the incorporation of a known road network in the processing chain is possible for detecting the targets and estimating their corresponding positions, velocities and moving directions.

Nowadays, different ground moving target indication (GMTI) algorithms are available in the literature for traffic monitoring applications. In particular, a fast dual-channel processor based on a priori knowledge information is presented in [2], where the positions of the vehicles are obtained through the intersection between the range-compressed moving target signals and the road axes mapped into the data array. Nevertheless, a number of false detections are obtained due to signals originated from adjacent roads, as depicted in **Figure 1**. The main ideas for recognizing and discarding these false detections are shown in [3], where the PD STAP was incorporated into the processing chain with the aim to achieve a robust estimation of the direction-of-arrival (DOA) angle of the detected signals (cf. **Figure 1** right). Although the PD STAP theoretical performance is presented in [3], the algorithm itself was not implemented nor tested.

The proposed algorithm combines the well-known PD STAP processor with a known road network obtained from the OSM database. The PD STAP was chosen due to its sensitivity to both low and high range velocities, its true clutter suppression and its accurate target position estimation capabilities. Moreover, the PD STAP is a reduced-rank method which offers computational burden mitigation and improved statistical convergence [4].

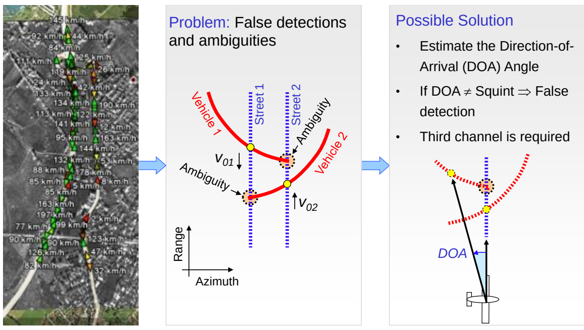

Figure 1: False detections due to adjacent roads (left and center) and possible solution for recognition (right).

2 Algorithm

The principle of the proposed GMTI algorithm is shown in **Figure 2**. There are several ways to combine the road network with the PD STAP. Three promising solutions are:

1. Use the algorithm from [2] and estimate the DOA for each detection using the PD STAP.
2. Perform the conventional PD STAP and assign each detection to the closest road point in a post processing step. As a result, the difference between the estimated position and the closest road point can be measured to decide whether the detection corresponds to a real target or a false detection.
3. Extend the algorithm from [2] so that more than only one squint angle (or DOA angle) of interest can be used successively for mapping the road into the range compressed data array.

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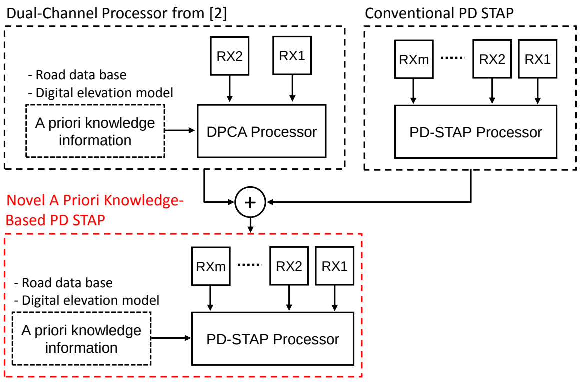

Figure 2: Principle of the proposed GMTI algorithm.

The first solution has the advantage that real-time processing is feasible without the need for high computational power. Nevertheless, since only a single aspect angle is considered, the probability of detection might suffer. The second solution requires at least the same high computation power as the conventional PD STAP. Even though, due to the block processing, the target can be observed over a wider aspect angle range determined by the two-way 3dB azimuth antenna beamwidth. Thus, an increased probability of detection is expected compared to the first solution. The third solution might be the best compromise between the probability of detection and the computation time. This paper shows and discusses the results obtained with the second solution.

The PD STAP is well-known in the literature and is used here to suppress the clutter and to estimate the target's Doppler frequency, slant range and DOA. These parameters are necessary for computing the range velocity and the position of the target. In this sense, the target's slant range velocity is given by the famous STAP equation:

$$v_{sr} = \cos(\hat{\Psi}_{DOA})\, v_p - \frac{\lambda}{2}\hat{f}_a\,, \qquad (1)$$

where v_p is the platform's velocity, $\hat{\Psi}_{DOA}$ is the target's estimated DOA angle measured with respect to azimuth, and $\hat{f}_a$ is the target's estimated Doppler frequency. The target's position in ground range and in azimuth can be expressed respectively as:

$$y_t = \frac{r_{10}}{\sin(\theta_i)}\sin(\hat{\Psi}_{DOA})\,, \qquad (2)$$

$$x_t = x_p + r_{10}\cos(\hat{\Psi}_{DOA})\,, \qquad (3)$$

where r_{10} is the target's slant range, θ_i is the incidence angle and x_p is the platform's position. The distance between the estimated position of the target and its closest road point is measured in order to decide whether the target corresponds to a true road vehicle or to a false detection. If the first condition is fulfilled, then the target is repositioned to its closest road point, otherwise it is discarded. The target's velocity on the road is given by:

$$v_t = \frac{v_{gr}}{\sin(\alpha_r - \alpha_p)}\,, \qquad (4)$$

where $v_{gr} = v_{sr} / \sin(\theta_i)$ is the target's ground range velocity, α_r is the road angle with respect to azimuth and α_p is the platform heading angle with respect to the easting axis of the Cartesian UTM coordinate system [2]. Finally, the target's moving direction is given by:

$$\alpha_t = \begin{cases} \alpha_r\,, \mathrm{sgn}(v_t) = +1 \\ \alpha_r - 180°\,, \mathrm{sgn}(v_t) = -1 \end{cases}\,, \qquad (5)$$

where $\mathrm{sgn}(\cdot)$ denotes the sign function.

3 Experimental Data

The proposed processor was tested using real pseudo 4-channel data (i.e., aperture switching data) acquired by the DLR's airborne system F-SAR. The flight campaign was conducted in February 2007 over the Allgäu airport in Memmingen, where five controlled cars were considered (data take ID: rc07trmrad0101). A detailed experiment description and radar parameters are given in [5]. The data were processed using blocks with 1024x128 range/Doppler samples, and the beamformers were applied using DOA angle steps of 0.1 degree within an interval determined by the azimuth antenna beam width.

The experimental results are shown in **Figure 3**. The optical reference data (acquired simultaneously with the radar data) are shown at the top left, where the cars 1 to 4 move on the edges of the runway, while Car 5 moves "off-road" in circle. The radar detections from the five cars are shown at the bottom as a Google Earth overlay. The detections are shown before (circles) and after (triangles) the use of the a priori knowledge information, and the colors are related to the velocities of the cars. Moreover, the triangles point to the moving direction of the cars, and the white lines show the distance between the vehicles and their closest road points.

It is important to point out that the center of the runway is used as the road axis. Thus, since the runway's width is approximately 30 m and the cars move on the edges, a relatively large offset (of around 15 m) is introduced. Generally, the width of the conventional road lanes is in the order of 2.5 m and thus the offset to the road axis is much smaller in real road data scenarios. The road axis uncertainty is in the order of 5 to 10 m for the OSM.

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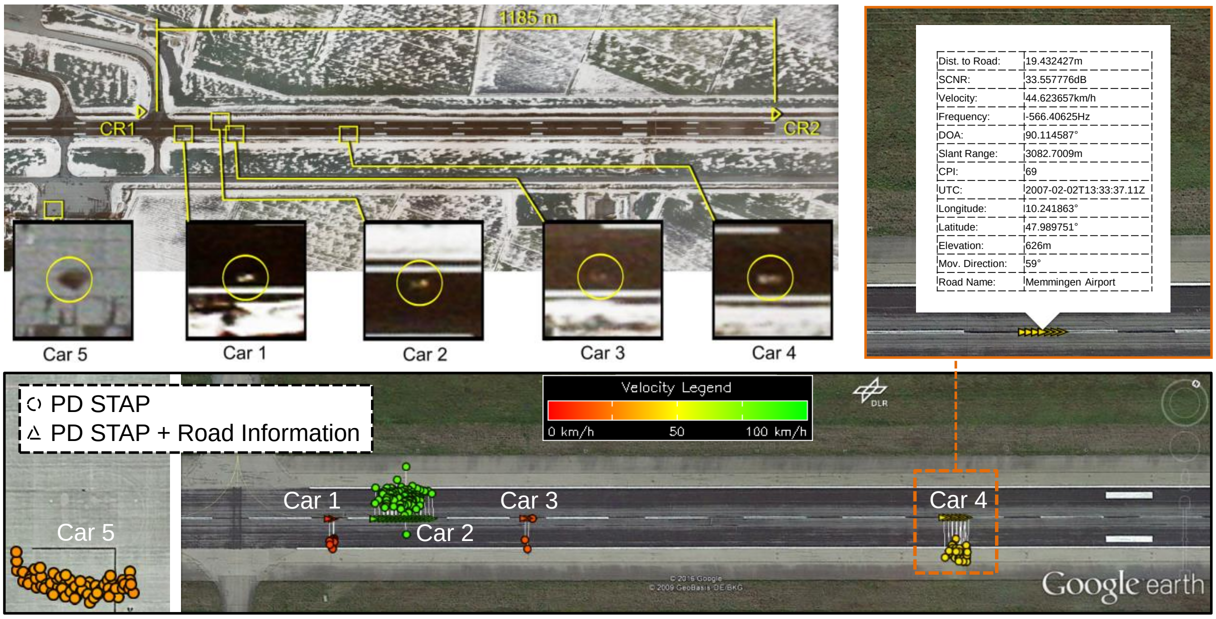

Figure 3: Allgäu airport in Memmingen (data take ID: rc07trmrad0101). Optical reference data (top left); Google Earth images overlaid with radar detections before (circle) and after (triangle) using a priori knowledge information (bottom); detail of Car 4 showing the estimated parameters at the instant 13:33:37.11 UTC [2] (top right). The Car 5 is detected by the PD STAP, whereas it is discarded after applying the road information once it moves "off-road".

The detections of Car 4 are shown in detail at the top right. At the time instant 13:33:37.11 UTC the estimated velocity of Car 4 is around 44.62 km/h, which agrees with the DGPS reference data presented in [2]. The PD STAP was able to detect all the cars several times due to the small data blocks used (i.e. 128 azimuth samples). Nevertheless, Car 5 is rejected after applying the road information, since it moves "off-road".

Figure 4 shows the velocity distributions of the detected cars before (top) and after (bottom) the use of a priori knowledge information. In this case, once the road information allows discarding the detections that lie far from the roads, the result is a clear histogram where the cars 1 to 4 can be easily identified. In addition, as far as the cars have moved nearly in across-track direction, their estimated range velocities were practically their velocities on the road.

Figure 5 shows the signal-to-clutter plus noise ratio (SCNR) distributions of the detections before (top) and after (bottom) the use of the a priori knowledge information. In this case, one notes that the weak detections (i.e., SCNR inferior to 5dB) lied far from the roads and thus were discarded after using the road information. Alternatively, the SCNR in the PD STAP output also suggests that an additional threshold, based on a minimum SCNR value, could be placed in order to discard most of the false detections.

To sum up, the estimated geographical positions and the velocities on the road agree with the optical reference data presented in [2].

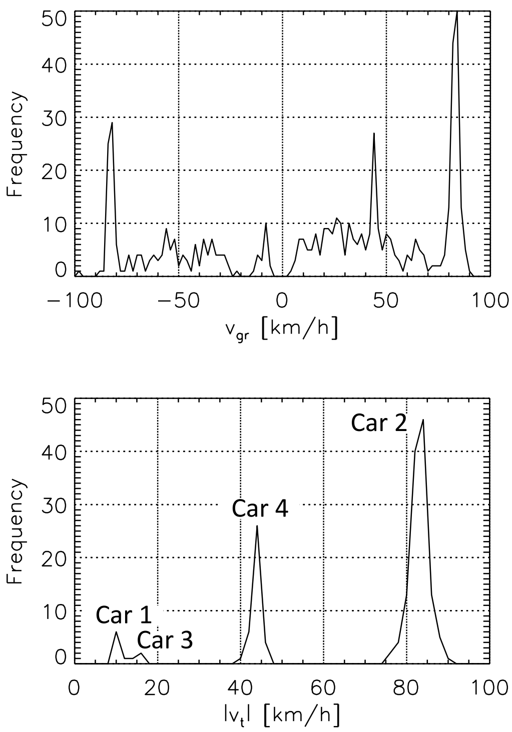

Figure 4: Velocity distributions before and after using a priori knowledge information: ground range velocity estimated by the PD STAP (top); absolute velocity on the road (bottom).

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The proposed processor was also verified using a data take that includes a real autobahn traffic scenario. The flight campaign was conducted in October 2013 over the Ammersee region, in South Germany (data take ID: 13vabene0204). The preliminary GMTI result is shown in **Figure 6**, where several customary road vehicles have been detected on the highway A96 as well as in residential roads. The roads included in the database are highlighted in white color.

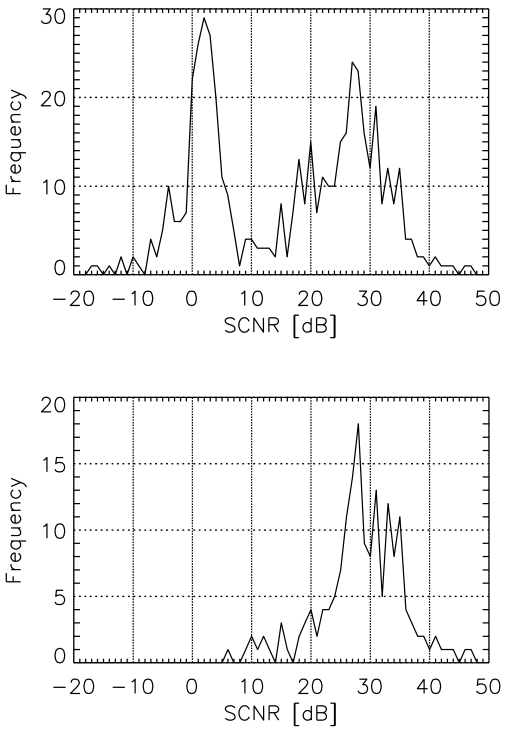

Figure 5: SCNR distributions before and after using a priori knowledge information: PD STAP output (top); detections repositioned onto the roads (bottom).

As far as several detections are obtained for each single vehicle, a further clustering step and a tracking algorithm are foreseen in the future. **Figure 7** shows the velocity distribution (top) and the SCNR distribution (bottom) of the vehicles depicted in **Figure 6**. The velocity distribution seems to be compatible with the speed limits, since most of the fast cars (i.e., velocities higher than 70km/h) are moving in the highway A96, while the slow cars are moving in the residential streets.

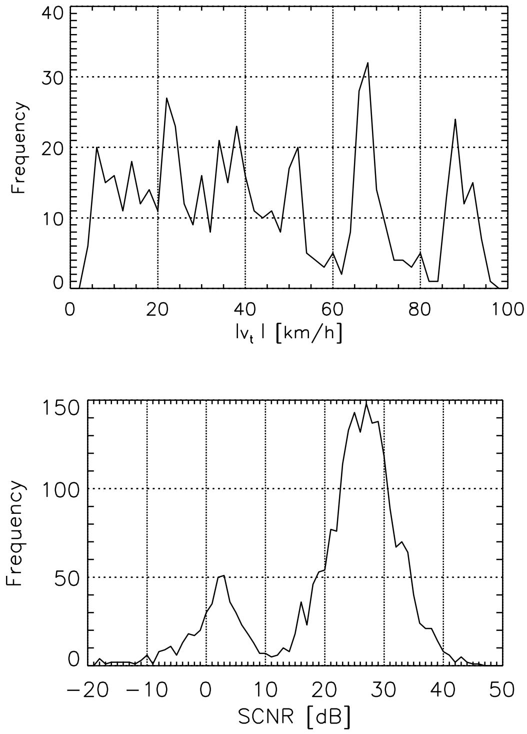

Figure 7: Velocity distribution (top) and SCNR distribution (bottom) of the vehicles depicted in **Figure 6**.

Figure 6: Ammersee region (data take ID: 13vabene0204). Google Earth image overlaid with radar detections after using the road information. The cars (triangles) were automatically detected and their parameters were estimated using the proposed processor. The roads included in the database are highlighted in white color (preliminary result).

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4 Conclusions

This paper shows the first experimental results obtained with our novel a priori knowledge-based processor. The combination of the well-known PD STAP with a road network revealed a powerful processor able to detect both slow and fast targets, and to discard detections that lie far from roads. For the results presented in this paper, a displacement offset limit of 20 m was set in order to decide whether the target corresponds to a particular road or not. Alternatively, the offset limit can also be obtained adaptively, e.g., as a function of the slant range velocity and the SCNR of the target. Suitable methods are currently under investigation. We will not limit our further investigations to the data takes whose results are shown in this paper. We have a large pool of multi-channel F-SAR data takes containing real highway traffic scenarios with dozens or even hundreds of vehicles.

References

[1] OpenStreetMap - The Free Wiki World Map, Jul. 2009. Available: http://www.openstreetmap.org

[2] S.V. Baumgartner, and G. Krieger, "Fast GMTI Algorithm For Traffic Monitoring Based On A Priori Knowledge," IEEE Trans. Geosci. Remote Sens., vol.50, no.11, pp.4626-4641, Nov. 2012.

[3] S.V. Baumgartner, and G. Krieger, "A priori knowledge-based Post-Doppler STAP for traffic monitoring applications," in Proc. IGARSS, pp.6087-6090, 22-27 Jul. 2012.

[4] W. L. Melvin, "A STAP overview," in Aerospace and Electronic Systems Magazine, IEEE, vol.19, no.1, pp.19-35, Jan. 2004.

[5] S.V. Baumgartner, M. Gabele, N. Gebert, R. Scheiber, G. Krieger, K.-H. Bethke, and A. Moreira, “Digital Beamforming and Traffic Monitoring Using the new FSAR System of DLR,” in Proc. IRS, Sep. 2007.

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