Dual-Platform GMTI: First Results With The TerraSAR-X/TanDEM-X Constellation

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Abstract: *First ground moving target indication (GMTI) and parameter estimation results obtained with the German TerraSAR-X/TanDEM-X radar satellite constellation are presented and discussed in the paper. For processing a dual-platform SAR-GMTI algorithm developed by the authors was used. This algorithm enables the estimation of the true geographical positions, the velocities and the headings of the detected moving vehicles with high accuracy.*

1. Introduction

Originally synthetic aperture radar (SAR) was designed for imaging the stationary world, independent of sunlight illumination and weather conditions. However, during the past years, also monitoring of land and maritime traffic has evolved to an important research topic. Targets which are not stationary but moving may cause some peculiar effects in the SAR images: in general they appear blurred and displaced from their actual positions. Thus, different signal processing approaches are needed for monitoring such targets reliably. In particular the objectives of a SAR-GMTI processor are to detect the moving targets, to estimate their actual positions and velocities as well as their headings.

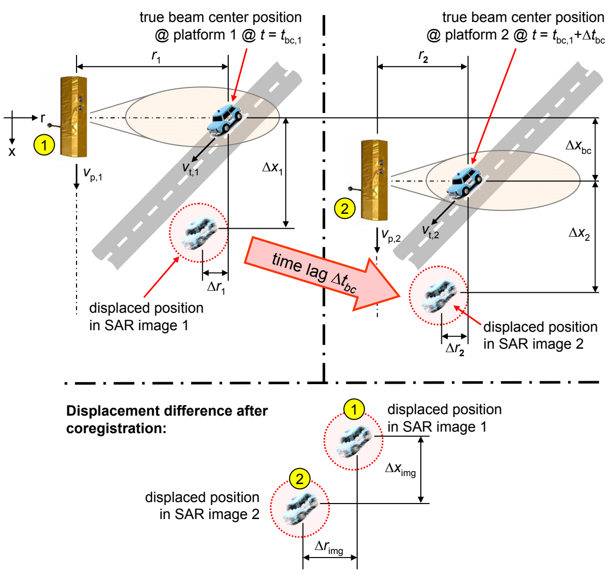

Figure 1: Moving target displacements in the SAR images acquired with the first (top left) and second platform (top right). The displacement difference is shown at the bottom.

One of the most critical parameters to estimate, especially with a spaceborne SAR-GMTI algorithm, is the moving target's actual position. Having only one single platform with two receiving antennas (e.g. one single TerraSAR-X satellite), the errors of the position estimates may be in the order of hundreds of meters if only the noisy and clutter disturbed along-track interferometric (ATI) phases are exploited [1]. For a more reliable position estimation the incorporation of a priori knowledge in the form of a road database is necessary [2]. However, land areas that contain many parallel roads are problematic since the target assignments to the correct roads might fail. A further drawback of such an approach is that targets moving on open land and open sea cannot be monitored at all.

To overcome these drawbacks we have developed a novel SAR-GMTI algorithm combining the data acquired with two SAR platforms, i.e. the German TerraSAR-X and TanDEM-X satellites, separated by a large along-track baseline [3]. This SAR-GMTI algorithm enables a reliable and accurate estimation of the actual position, the velocity and heading of each detected moving target without the need of a priori knowledge. Thus, also targets moving on open land and on open sea can be monitored.

In the following sections the principle of the SAR-GMTI algorithm is explained and the first SAR-GMTI results obtained with the TerraSAR-X/TanDEM-X constellation are presented and discussed.

2. Principle of the SAR-GMTI Algorithm

The basic idea of the SAR-GMTI algorithm is sketched in Fig. 1. Having both satellites separated in along-track direction, one and the same area on ground is imaged by TerraSAR-X and TanDEM-X at slightly different times. Thus, one and the same moving target appears on different 'displaced' positions in the images, since it has moved between both radar acquisitions (cf. Fig 1 bottom). The displacement difference of the moving target can be measured with high accuracy using a two-dimensional cross-correlation. From the estimated displacement differences the actual positions, the velocities and the headings of the detected moving targets can be estimated with high accuracy. The mathematical background and a more detailed description of the algorithm is given in [3] and should not be repeated here.

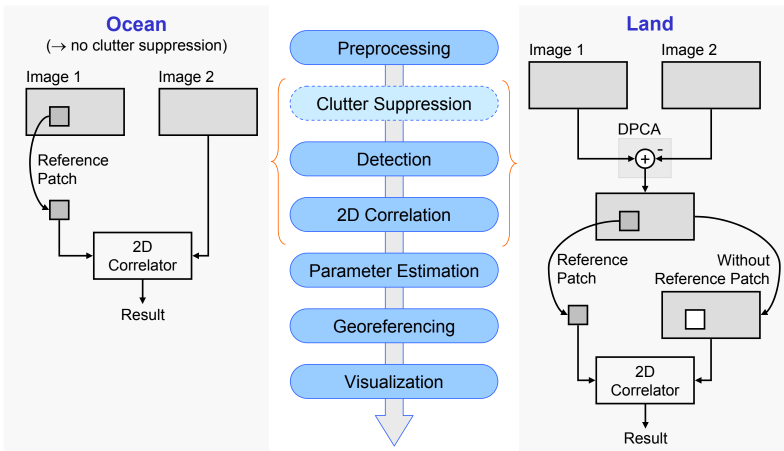

Figure 2: Simplified flow chart of the SAR-GMTI algorithm (middle). Some of the processing steps are different, depending whether maritime (left) or land traffic (right) should be monitored.

A simplified flow chart of the implemented SAR-GMTI algorithm is shown in Fig. 2. During preprocessing conventional SAR images are generated taking into account the full bandwidth given by the pulse repetition frequency. 'Image 1' and 'Image 2' are the images acquired with

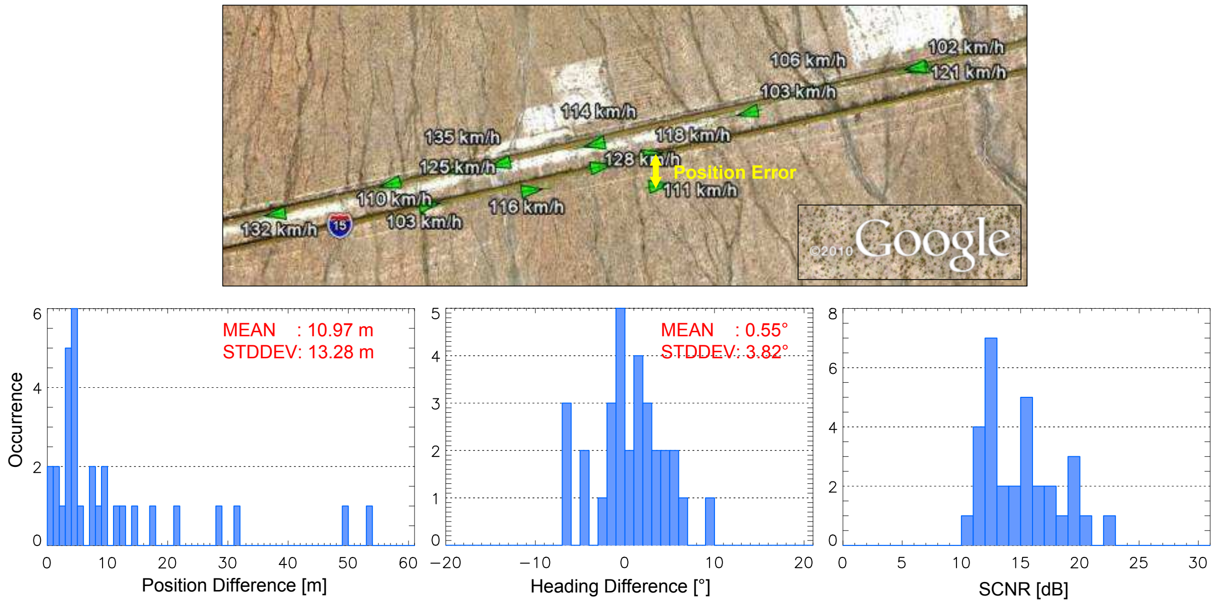

Figure 3: Land traffic monitoring results obtained from the Interstate 15 date take (top: Google Earth image with the detected vehicles depicted as colored triangles; bottom: histograms of the position differences (left), the heading differences (middle) and the SCNR (right)).

the first and second platform, i.e. with TerraSAR-X and TanDEM-X. Clutter suppression using the displaced phase center antenna (DPCA) technique is carried out only if land traffic should be monitored (cf. Fig. 2 right). Parameter estimation is performed as explained in [3]. After georeferencing a 'Keyhole Markup Language' (KML) file containing the SAR-GMTI results is generated. The results can then be visualized using Google Earth.

3. First Experimental Results

In 2010 during the early commissioning phase of TanDEM-X several GMTI data takes of different test sites have been acquired with the aim to evaluate and verify the novel SAR-GMTI algorithm. The TerraSAR-X and TanDEM-X satellites were operated in the pursuit monostatic mode [4]. At the time of data acquisition the along-track baseline between both satellites was in the order of 20 km, corresponding to a time lag of approximately 2.5 s. This is just the time lag promising the best performance of the proposed SAR-GMTI algorithm [3].

3. 1. Land Traffic

One test site used for monitoring land traffic was the Interstate 15 in the north-east of Las Vegas. It was not possible to determine the detection rate of the SAR-GMTI processor since no ground truth data was available. However, the position estimation accuracy could be computed by measuring the residual offsets between the estimated vehicle positions and the known geographical positions of the road axes, which are obtained from a road database. The heading difference was

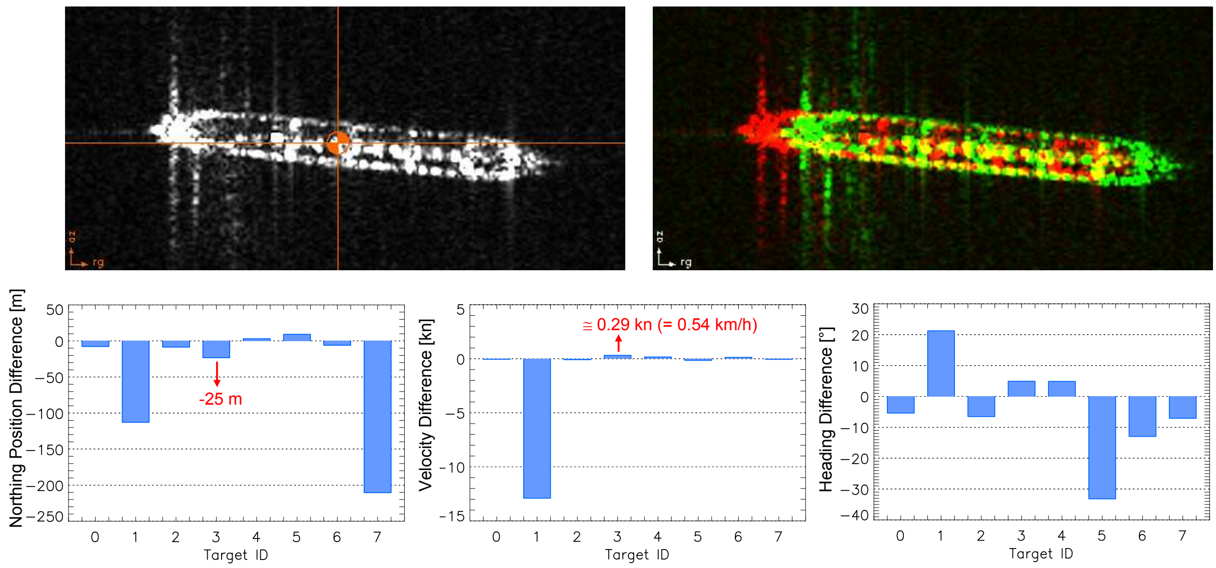

Figure 4: Maritime traffic monitoring results obtained from the Strait of Gibraltar data take (top left: TerraSAR-X image of a vessel, the orange cross marks the point used for georeferencing; top right: superposition of the TerraSAR-X (red) and TanDEM-X (green) image of the same vessel, the vessel's motion can clearly be recognized; bottom: measured northing position (left), velocity (middle) and heading differences (right)).

computed by comparing the estimated heading with the known direction of the road axis.

The preliminary evaluation results are shown in Fig. 3. In total 31 detected vehicles with signal-to-clutter plus noise ratios (SCNR) from 10 to 23 dB were considered for evaluation. False detections have been precluded. The mean of the position differences is 10.97 m, corresponding to a velocity difference of 0.57 km/h. The mean value of the heading differences is 0.55°, indicating that the two-dimensional velocity estimation, i.e. the estimation of the along-track as well as the across-track velocities, is very accurate.

3. 2. Maritime Traffic

Vessels have been monitored in the Strait of Gibraltar. Automatic identification system (AIS) data of the vessels were used as ground truth [5]. The parameter estimation errors of the SAR-GMTI algorithm are assessed by comparing the estimates with the AIS reference. One result is shown in Fig. 4. All eight AIS reference targets were detected automatically. For georeferencing the point of the centroid of the area of the vessel image was used (cf. Fig. 4 top left). Note that the position of the centroid is different from the position of the GPS receiver of the AIS. As a consequence the uncertainty of the computed position difference or the position error, respectively, depends on the vessel size.

The vessels have mainly moved in range direction, which differs only by 9.5° from the UTM easting direction. Thus, the UTM northing position difference shown at the bottom left in Fig.

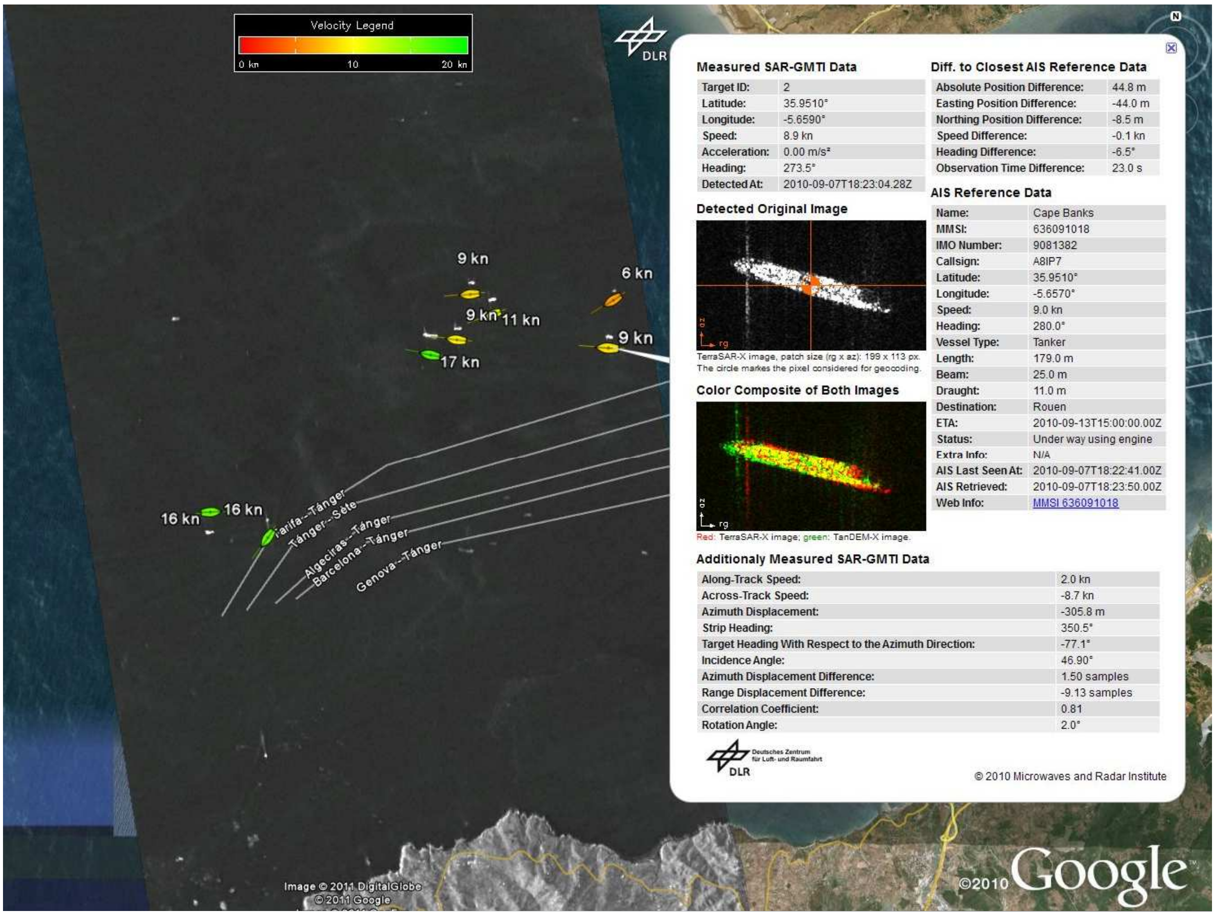

Figure 5: Google Earth image of the Strait of Gibraltar overlaid with the KML file from the SAR-GMTI processor output. The color coded symbols (color is velocity dependent) represent the automatically detected vessels on the estimated 'true' positions. Also the displaced vessel images in white color are visible.

4 is directly related to along-track position error. The uncertainty of the position difference is in the order of half of the vessel width. The position difference of -115 m of the target with ID 1 is not reliable, since the correlation coefficient of the two-dimensional cross-correlation was small. For target 7 the time difference between the AIS and the SAR data was 440 s, which is quite large. It can be assumed that in this case the AIS position extrapolation, for which a constant vessel velocity and heading are assumed, gives not the correct result. Therefore also the measured position difference of target 7 is not reliable. The maximum position difference is -25 m if the two outliers are discarded.

The maximum velocity difference is 0.54 km/h or 0.29 kn, respectively, if again target 1 with the small correlation coefficient is not considered (cf. Fig. 4 bottom middle). Hence, the measured velocity difference is in the same order as for land traffic.

The heading differences are almost below $\pm 10^{\circ}$, except for two outliers (cf. Fig. 4 bottom right): target 5 has made a strong turn between both observations and the results for target 1 are again not reliable. The low heading difference indicates that also for extended targets like vessels the two-dimensional velocity estimation is very accurate.

In Fig. 5 the maritime traffic monitoring results are shown as a Google Earth overlay. The user can click on a vessel symbol to open a window showing all the relevant information about the vessel (cf. Fig. 5 right). In this example also the automatically merged AIS reference data is shown.

4. Conclusion

The presented preliminary results confirm that the proposed and implemented dual-platform SAR-GMTI algorithm is well suited for land and maritime traffic monitoring. For vehicles moving on land the position estimation accuracy is on average smaller than 11 m. This is a really impressive value, especially under the aspect that no other SAR satellite system has ever achieved such a moving vehicle position estimation accuracy, particularly without the use of a road database or other a priori knowledge. Still more of the acquired GMTI data takes need to be evaluated in order to statistically confirm the first results presented in this paper.

References

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