Traffic Monitoring With TerraSAR-X

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ABSTRACT

The aim of the project „Traffic Monitoring with TerraSAR-X" and the motivation for a satellite based traffic monitoring is summarized. The features of the TS-X Traffic Processor TTP and the need for Multi-Channel SAR sensors are explained. Two examples of the first results of the innovative data processing system are presented.

1. INTRODUCTION

The objective of the project (Proposal LAN0226) is the demonstration of space borne traffic monitoring with the radar satellite TerraSAR-X (TS-X). The derived information shall be delivered to end-users and traffic information centres in near real time. In cooperation with beta-users it shall be demonstrated how already existing traffic information from other sensors can be improved with TS-X data.

Precise and up-to-date traffic information of large areas, like the measured instantaneous travel times between knots of the road network are important parameters for an optimal route planning. The fast detection of dense traffic or congestion and the timely information of the motorists is mandatory, in order to give them enough time to adapt themselves to the situation. Furthermore the information must be reliable before the motorists trust it and delay their trip, take another route or shift to public transportation. The final goal is to achieve an optimal use of the road network and to minimize the travel time and fuel consumption.

Conventional traffic measurement techniques like induction loops, cameras or overhead sensors on bridges work only locally and only available on main routes and in metropolitan areas. Floating car data and traffic information derived from mobile phones in cars are insufficiently available from roads with little traffic. The TS-X with it's electronically steer able antenna can react in principle very fast on demands for certain areas. It can reach vast regions in relatively short time and can perform traffic measurements completely weather independently. It can operate world wide because no ground installations are required for the measurements.

The TerraSAR-X was the first radar satellite equipped with a "Dual Receive Antenna Mode" (DRA-Mode) which allows for the recording of two radar channelss with a short time lag. One channel is dedicated to the front antenna and the other one to the aft antenna half. Such multi-channel systems are an important prerequisite for the detection of moving objects in the SAR data [1].

The first speed measurements of road traffic from the Earth orbit have been performed in the year 2000 with the German X-SAR radar onboard the Shuttle Radar Topography Mission (SRTM). A floating car equipped with a GPS receiver and several trucks on the A9 motorway north of Munich have been measured [2]. In the beginning of the TS-X Traffic Monitoring Project no data where available from a satellite. Therefore the first experiments were performed with the E-SAR airborne radar of DLR´s Microwave and Radar Institute [3 - 6].

An aircraft sensor can achieve a much better temporal coverage than a satellite. On the other hand satellites work completely independent of weather and cover large areas much faster than an aircraft. Finally they can reach each place on Earth without the permission of air traffic controllers.

2. THE TRAFFIC PROCESSOR

The TerraSAR-X Traffic Processor (TTP) which is depicted in Figure 1 was derived from a modified version of the TerraSAR-X Multi-Mode SAR Processor (TMSP) [7] and enhanced with additional ground moving object detection software modules. One core part of the new system designated "TTP" is a GIS data base, from which the road network for the currently processed scene is automatically extracted. The GIS data is used in several ways in the processor, e.g. for predicting the data segments containing roads and which must be evaluated at all. This reduces processing time significantly.

The azimuth displacement of moving objects is an inherent effect of SAR imagery and has to be considered. On the other hand this effect can be used to precisely determine the speed of a moving object on a certain road. The GIS data base is used to predict parameters of the moving objects depending on their position in the radar image relative to the road. Also the Along Track Interferometric (ATI) Phase is used for the speed measurement and the results are compared. After this consistency check of the detection results the output data set is created in KML format. It can

directly be displayed in Google Earth and contains the location, heading and speed of each individual detected moving object. Due to its small data volume of the result file it can be automatically send out by EMail to specified users. The different algorithms and methods used in the TTP are described in a series of papers [8 - 14].
The hardware platform is a 8-processor parallel computer with dual-core CPUs running under Linux. The programming is performed in C++. First trials indicate that the SAR- and traffic-processing can be finished within 15 minutes after data reception.

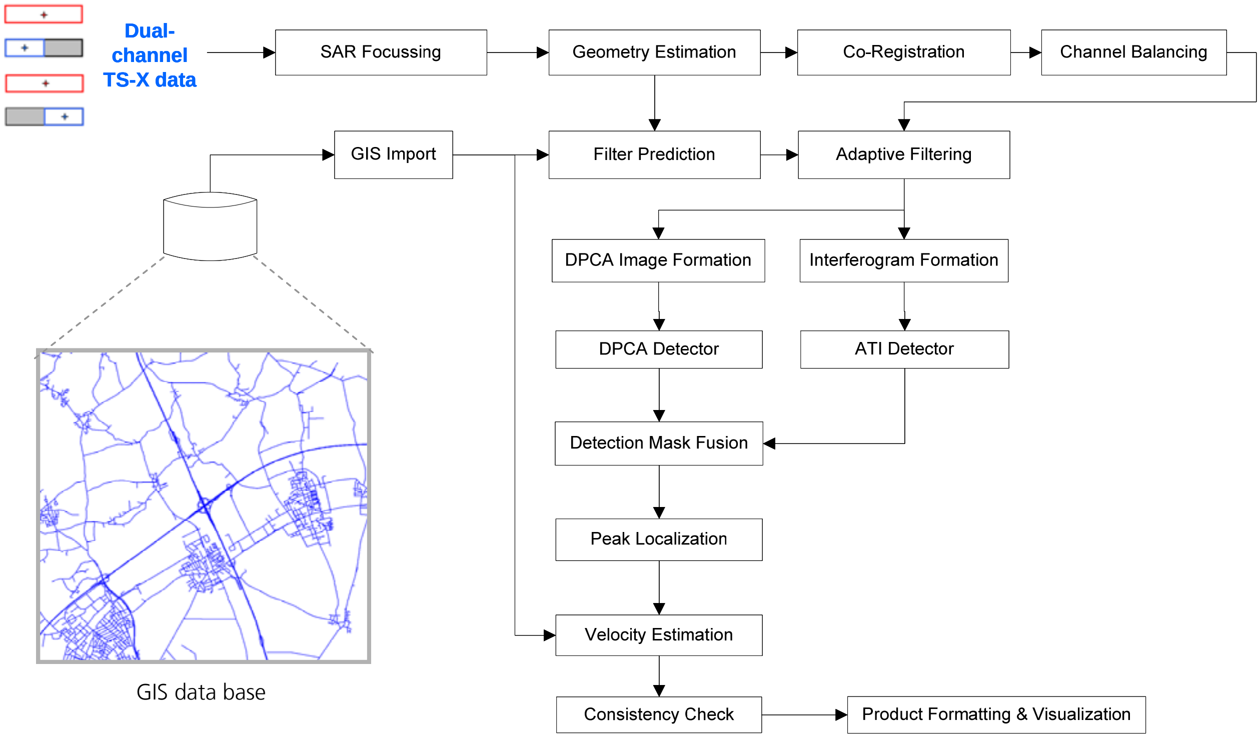

Figure 1 Block Diagram of the TerraSAR-X Traffic Processor TTP

3. USE OF MULTI-CHANNEL DATA

Due to the short along-track baseline (separation of the phase centers of the aft and front antenna halves) of TS-X the ATI-method can only be used for fast vehicles and with an across-track component of their velocity. Moreover the DRA-mode has not been made available yet and the alternate method of "Aperture Switching" had to be used [15]. This method uses only one receiver channel but a doubled PRF. The front and aft antenna halves are from pulse to pulse alternately attenuated on reception. The large drawbacks against the DRA-mode are a worsened SNR of 3dB and a halved swath width. For the use in the operational TS-X ground segment environment the DRA-mode has another big advantage over the Aperture Switching method. In the DRA-mode not only the two channels of the front and aft antenna will be available, but also the sum-channel of the front and aft antenna which is identical to the standard operation mode. This implies that the users of standard data products can always receive the data sets they are used to.
The two channels of TS-X are used in the Traffic Processor also to generate so called "DPCA" images with reduced clutter. It would be highly desirable for future sensors to have even more channels and a larger separation of the phase centers of the antenna segments. This would lead to a much higher sensitivity for slower vehicles and it will be achieved with the TanDEM-X mission. Due to the boosted ATI-phase the traffic measurements in more complex road networks will become facilitated. It will even be possible to measure the velocity and heading of vehicles in regions with no roads like in desserts.

4. FIRST EXAMPLES

For the system check-out various TS-X command setings had been programmed and data acquisitions had been performed over motorways in Germany, France, Switzerland and California / USA. The main test site is the A4

motorway west of Dresden / Germany, which was monitored for nearly one year. Intensive ground truth measurements with video cameras on bridges were performed. Furthermore airborne high resolution digital cameras have been used to take pictures of the traffic on the A4 just in the moment of the TS-X data acquisition. The digital photography's were precisely coregistered with the TS-X image in order to be able to verify each single vehicle on a 3.4 km long road section. A first evaluation of one data set revealed a TS-X detection rate of trucks of 65% and of passenger cars of 30%. It is assumed that this rate is sufficient to characterize the state of the traffic because traffic problems normally occur only in dense traffic.
The low detection rate of passenger cars is due to their weak radar cross-section and high dependence of the radar aspect angle. In the course of the project we have performed intensive measurements of passenger cars using the airborne sensor E-SAR [16 - 18].

Figure 2 shows a section of our test site on the A4 motorway west of Dresden. The TS-X scene was acquired on April 18th, 2008 at 7:25h local time with the Aperture Switching Mode and 300MHz chirp bandwidth. In this particular sensor configuration the radar Pulse Repetition Frequency (PRF) as well as the signal sampling rate is very high. Due to data rate limitations the swath width is limited to 7 km in this case. On the road section 73 vehicles were detected, symbolized as little triangles, color-coded according to their velocity and superimposed to the SAR image. The velocity statistic in the lower left corner of the image represents the eastbound traffic. The peak around 85 km/h corresponds to the speed of the trucks.

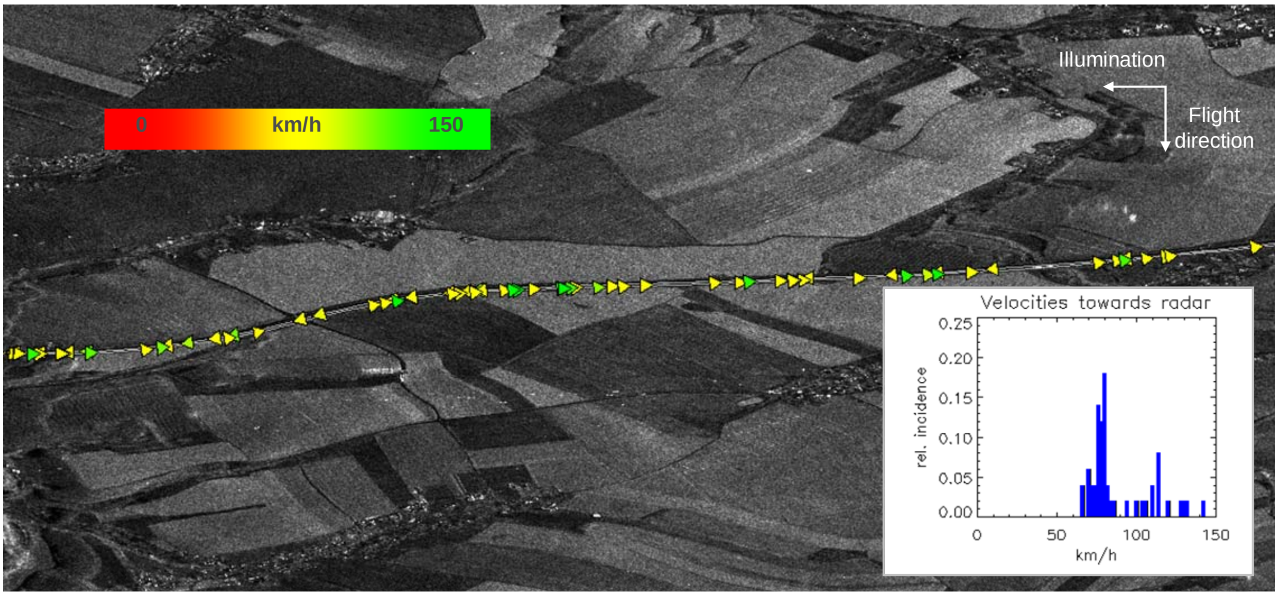

Figure 2 TerraSAR-X Traffic Measurement on the A4 Motorway West of Dresden, Germany

The generation of the next example was triggered by an air cargo forwarding agent who's client was a human relief organisation. Heavy rainfalls hit large parts of Honduras in Central America on October 20th, 2008 and more than 40.000 people had to be evacuated. 50% of the roads were affected by flooding and landslides and it was unclear weather the relief supplies could be carted off the San Pedro airport in the North of the country. Within 24h a TS-X stripmap acquisition in Aperture Switching Mode was programmed and executed. In Figure 3 the radar image is overlaid over a Google Earth map. The airport is located at the centre left. In the north of the airport close to a canal dark areas can be seen which are probably wet or even flooded. The traffic processing was performed for the main road from El Pedro to El Progreso. It was shown that there was fluent traffic at the time of the TS-X snapshot. At least at this time it should have been possible to use the road for the transport of the relief supplies.

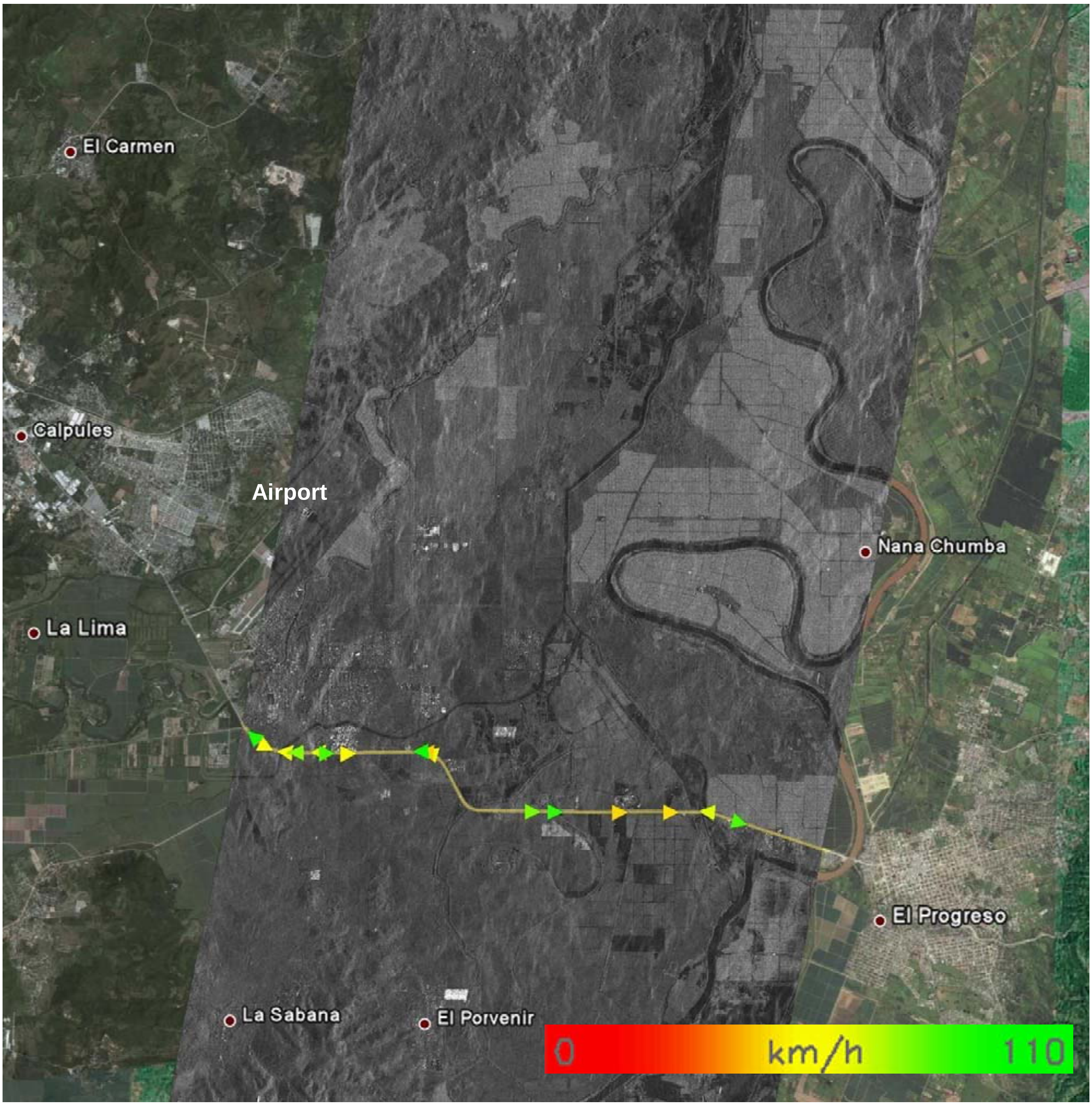

Figure 3 TerraSAR-X Traffic Measurement From October 23rd, 2008 Near the El Pedro Airport In Honduras

5. APPLICATIONS OF THE SYSTEM

The main goal of the project is the demonstration of the generation of **up-to-date traffic information.** In comparison with other traffic data collection systems TS-X is unique because it works worldwide and doesn’t require any ground installations. Furthermore the observation areas can be changed quickly and in principle a fast response on user requests is feasible.

However, with one satellite only snapshots of the traffic situation are possible. For a global observation system with a revisit time in the order of 15 minutes a large satellite constellation would be necessary. A first step in this direction can be achieved in cooperation with Space Agencies which have already appropriate SAR satellites in orbit, e. g. the Radarsat-2 in Canada. A large constellation of SAR satellites may become reality in cooperation with other users, because other applications have similar requirements like maritime security where a global ship monitoring is on demand.

In the case of **catastrophes** like Earth quakes and large floods, wild fires and accidents in large industrial facilities the rescuers need precise information about the road status and weather them are still passable. With the TS-X Traffic Processor it can be proven which roads are obviously in use and can be utilized for relief supplies, ambulances, evacuations, etc. The Traffic Processor can provide in general an additional layer in Geographical Information Systems and may also be of interest for security applications.

Speed measurements with Synthetic Aperture Radar are very precise and once a vehicle is detected and the associated road track is known the accuracy is in the order of 2 to 3 km/h. Therefore, the satellite can be used to check ground installations like induction loops and overhead sensors. It may not only be used for the **verification of** single devices, but also to verify new traffic measurement techniques (like the analysis of mobile phone data) and even overall **traffic information systems**.

6. SUMMARY AND OUTLOOK

Traffic Monitoring is an interesting new application for SAR satellites. Beside the generation of up-to-date traffic information for large areas it can be used to verify other traffic measurement and information systems. In catastrophe and crisis areas it will be used to identify roads which may be used for relief supplies and evacuations.

For an operational use and for even better data quality the DRA-Mode has to be used and integrated into the standard production chain of the TS-X Ground Segment. In order to improve the revisit time data from other satellites like the Radarsat-2 could be used. With the upcoming TanDEM-X mission [19] it can be demonstrated how more receive-channels and longer ATI-baselines can lead to a significant improvement of the data products.

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