Traffic Monitoring With TerraSAR-X

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Abstract
The paper provides a brief summary of the applications of space based traffic monitoring with SAR and describes the ground segment and the traffic processor which is under development at DLR. The problems for detecting cars in SAR images are summarized. A group antenna concept for TerraSAR-X is suggested.
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The Need for RADAR Based Traffic Monitoring
For the optimization of road traffic and the planning of new infrastructure the availability of traffic data is a prerequisite. State of the art is the use of induction loops, radar sensors on bridges and cameras. These sensors provide only local information and do not deliver the complete picture of the traffic situation, e. g. on an overall section of a motorway. The best solution is the view from the top, like from an aircraft or a satellite. In this case a large area can be overlooked and the traffic in a larger region can be analysed [1]. Typical parameter which are on demand are the traffic density, the variation of the density over a road section, the percentage of trucks in the overall traffic, the average speed and the variation of the average speed over a section of a motorway and finally the length of traffic jams.

Airborne optical and infrared systems are rather mature and work partly already in real-time [2,3]. But the optical systems are dependent of sunlight and good visibility. The infrared systems work at night but fail at rain and snow fall. SAR is nearly weather independent and at low frequencies like L- and P-band it has even the capability to penetrate the canopy of trees. Furthermore there exist various possibilities to measure the speed of moving objects like the evaluation of the “train off the track” effect or the along track interferometric phase. Many algorithms have been developed for the so called “Ground Moving Target Identification” (GMTI) but need to be adapted to spaceborne sensors.

At DLR three combined projects in this field of “Radar and Traffic” have been started [4]:
- The “TS-X Data Products for Traffic Research” project is led by the Remote Sensing Technology Institute and is briefly described in this paper.
- “TRAMRAD: Space borne traffic data collection via radar” is a project led by the Microwaves and Radar Institute. Within this project, the design of the optimal future SAR sensor and satellite constellation to collect traffic data is developed.
- “RAVE: Space borne traffic data collection”, led by the Institute of Transport Research. This project deals with the user requirements and data product definitions from the traffic research point of view.

The TerraSAR-X Traffic Monitoring Demonstration Project

The TerraSAR-X remote sensing satellite is a public-private partnership between EADS-Astrium and DLR and is going to be launched in 2006 [6]. One of the science application projects is the demonstration of civilian traffic monitoring. This activity had its roots already in the year 2000 when the speed of a passenger car had been measured with high accuracy and trucks on a motorway have been detected in data from the Shuttle Radar Topography Mission (SRTM) [7]. This sensor had both an along-track and across-track baseline which complicates the measurement of velocities of moving objects. The TS-X will have a pure along track baseline and also the spatial resolution will be much better than with SRTM.

With TerraSAR-X SAR Along Track Interferometry is realised with the so called "Dual Receive Antenna” (DRA) mode [8]. While the overall antenna is used for transmission, two antenna halves are used for reception each linked to a separate receiver channel. For this upgrade, which has been introduced relatively late into the design of the satellite, no additional hardware was necessary. The second receiver channel was already existing as a redundancy. Figure 6 shows the satellite with the solar panel on the top and the SAR antenna at the bottom. The overall TS-X antenna is nearly 5m long, which leads an along track distance between the two phase centres of app. 2.5m. Due to the bi-static operation the effective along track baseline again halves. However, the sensitivity of this relatively short ATI baseline is well suited for the measurement of fast moving targets like motorcars.
Fig. 1: The radar antenna of the TerraSAR-X satellite (courtesy of EADS-Astrium) can be electrically split into two halves on receive.

Ground segment

DLR is developing a “Traffic Processor” as an extension of the TS-X Multi-Mode SAR Processor and of the baseline TS-X ground segment sketched in Fig. 2. This processor shall identify moving objects on the ground, determine their real position, their velocity, driving direction and classify the type (passenger car or truck). Furthermore the extension of traffic jams shall be measured. The traffic processor will be located in Neustrelitz next to the ground station where the data downlinks are recorded. For advantageous sites and traffic situations a near real time processing shall be demonstrated. The requirement is that the traffic information can be transferred to a traffic control center within 20 minutes after data reception. Here the data are merged with other information, drivers are informed, a traffic forecast may be generated and traffic data bases are updated. This demonstration phase is planned for the year 2008. First results of this project, which is currently in phase-A, have been described in [9, 10, 11, 12].

One major result is concerning the radar cross section of road vehicles. It has been found that trucks normally deliver a bright radar return under all aspect angles but the radar cross section of passenger cars turned out to be extremely dependent on the aspect angle. From 0 to 180 degrees the variation can be in the order of 10dB m$^2$ and furthermore the fading within a range of only a few degrees can reach again 10dB m$^2$ [13]. It has been disclosed in [4], that also a thin water layer on the asphalt can significantly influence the double bounce effect and can again lead to differences of the radar cross section again in the order of 10dB m$^2$. Therefore, under favourable conditions it may be possible to detect passenger cars in radar images, but it will probably be extremely difficult to measure exactly the number of passenger cars on a road section. Another fact which has to be taken into account is that moving objects defocus due to their motion and possible acceleration. Therefore special processing techniques are required.

Multi-Channel Receiver for TerraSAR-X

Efficient clutter reduction techniques are mandatory to be able to detect weak radar returns from moving objects. With the Dual Receive Antenna (DRA) mode of TerraSAR-X only the Displaced Phase Center (DPCA) method can be used for clutter reduction. The much more efficient space-time adaptive filtering techniques require multi-channel SAR systems [14,15]. Therefore, we would like to suggest analysing further a virtual 4-receiver channel configuration for the TerraSAR-X. The proposal bases on the idea that the need for multiple receivers can be overcome by multiplexing a single receiver between different antenna segments. With a PRF 4 times higher than the normally required PRF a 4-channel system could be realized like depicted in Fig. 3. The group antenna concept base on a spatial sampling at different phase centers. In principle this can be accomplished with microwave switches in the combiner network of a conventional planar antenna. However, also phased array antennas consisting of T/R-modules may be suited to switch the amplitude from pulse to pulse and to lay off overall antenna segments for short time cycles. It shall be pointed out that the spatial sampling can be realized by shifting segments of the transmitting antenna and or of the receiving antenna.
In order not to lose radiation energy we consider in our examples that the full antenna is used for transmission and only a part of the antenna is used for reception. The price which has to be paid for the additional channels is threefold:

1) The receiving antenna surface is reduced by the factor $n$, which is the number of virtual receiving channels.
2) The PRF has to be increased by the factor of $n$.
3) A much higher PRF will require a drastically reduced swath width.

Fig. 2: Baseline TS-X ground segment with extensions for the traffic monitoring project
Therefore, we propose to combine the multiplex approach (applying a multiple PRF) with the Dual Receive Antenna feature of TS-X. In this case the second receiver channel can be used to realize a 4-channel system which requires only a 2x PRF. This pulse rate is feasible in the TS-X strip map mode with a slightly reduced swath and is already used for the dual polarisation mode. Such a virtual 4-channel receiver system for TS-X is depicted in Fig. 4.

It has to be analysed whether this configuration is technically feasible and can produce useful results with the STAP technique. However, this method can also be applied for dual baseline along track interferometry or even combined along track and across track interferometry with TS-X. Fig. 5 shows how a SAR along track interferometer can be realized with only one receiving channel.
If the receiving antenna size of 1/n does not meet the performance requirements, e. g. for azimuth ambiguities one could consider an upgrade for the next generation TerraSAR-X satellite. We propose a relatively simple and lightweight extension which would enable for a 4-channel configuration where the receive antennas have half the length of TS-X main antenna (instead of one quarter the length like in the examples depicted in Fig. 3 and 4). This can be accomplished with an enlargement of the active main antenna with two receive only panels, similar to the X-SAR / SRTM outboard antenna (please note Fig 6). Both antennas for the front and aft end would be app. 2.5m long (half the length of the main antenna) and would have their own receivers. Together with the Dual Receive Antenna in the centre in total 4 receivers could then be used and the standard PRF would be sufficient. Applying the 2x PRF even eight channels could be realized. The two extra antenna panels may be stored inside the satellite bus and slide out after launch or may be fixed with hinges on the top and bottom of the bus and unfold after launch. Another advantage of the proposed antenna extension is that the baseline for along track interferometry and for the group antenna doubles. If even larger baselines are required, booms have to be used.

Fig. 6: **Extension of the TerraSAR-X** main antenna with two receive only antenna panels. A 4-channel configuration can be realised with the standard PRF and a 8-channel configuration with the 2x PRF.
Conclusion
The monitoring of road traffic is a new and challenging application of Synthetic Aperture Radar. The main advantages of SAR are the night and all-weather capabilities as well as the ability to cover large scenes. The TerraSAR-X satellite will act as a demonstrator for various GMTI techniques and for operational traffic data generation.

References