Space Borne SAR Traffic Monitoring

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Abstract

The need for world wide traffic monitoring with remote sensing means is described. The pros and cons of air borne and space borne sensor platforms are compared for this application. First results of automatic detection of moving objects in a TerraSAR-X scene are presented.

Introduction

In most countries road congestions and traffic jams induce enormous costs and pollution of the environment. Taking into account the order of the losses which are accounting to several billion Euros per country, even a small improvement of the situation could justify the deployment of new technologies like Synthetic Aperture Radar (SAR) satellites.
Traffic information can assist individuals to bypass congestion, but it can also help to improve the situation in the problem zone due to the reduction of new cars flowing into the area. Traffic information has to be reliable and up to date to persuade motorists to take a detour, to postpone or even give up their trip before they have started or to change to other transportation means like trains. SAR satellite technology can complement existing traffic information and help to overcome the problem.
Today’s traffic information and prediction systems base on models which need start values for each day. Ground sensors like induction loops and cameras are available only locally, while a space borne SAR overlooks a large area and can provide data from road segments where no other data are available. in contrast to simple traffic information advanced traffic management and control would probably call for a dedicated formation of SAR satellites, because it requires measurements of the traffic density and average speed for a road section at least every 15 minutes. At catastrophes like large floods as in New Orleans in 2005, earth quakes, volcano eruptions, road accidents with hazardous materials, fires or accidents in nuclear power plants it would also be highly desirable to have continued up to date road status and traffic information.
As soon as it is state of the art how a SAR satellite is optimally designed for traffic monitoring and the algorithms for the data processing in the ground segment are developed, the techniques will be included in future common SAR systems. Traffic information centre will order data from traffic hot spots and where no sufficient ground sensor-infrastructure is available. In that way they will complement their picture of the current traffic situation with satellite data.

Aircraft Versus Satellites

Up to now SAR sensors on aircrafts had to be used for traffic monitoring and it has been successfully demonstrated that it is possible to detect congestions, measure the speed of the cars and to derive travel times [1,2,3]. The advantages of the use of aircraft are as follows:

- They can continuously observe a certain area for several hours.
- The distance to the ground is quiet small which allows achieving good signal ratios and hence a high vehicle detection rate.
- It is much easier to test new sensor hardware on an aircraft than in a satellite.

- Aircraft can use in principle flight tracks and time of the day which is optimally for the mission.

However, the last point is not true for agglomeration areas where airspace is so crowded that it is very difficult to get flight permission. Unfortunately, these are the areas where the main traffic problems exist! Furthermore, small aircrafts can't fly at bad weather and low visibility, but these are the conditions where most road accidents happen. Another point of concern may be the acceptance in the public, because it is not desirable to have permanent air traffic for road surveillance over urban areas. A solution can be high altitude aircraft which are operating above the normal air traffic and the "weather".

The advantages of satellites for traffic monitoring are:

- They are extremely fast and can cross a country like Germany in the order of two minutes.
- They have a global coverage and the traffic monitoring can be performed in each part of the world.
- Satellites do not violate the sovereign rights of other countries.
- There are many other applications for SAR satellites, like security and maritime surveillance.
- As soon as a satellite is launched it doesn't consume fuel anymore and the maintenance costs are much lower than for aircraft.
- Satellites can't crash and hurt people.

The biggest advantage of satellites over aircraft is the much better coverage, which is due to their high speed of more than 25.000 km/h and their high swath width. The E-SAR [4] on a turboprop D0-228 aircraft, which was used to test SAR processing algorithms for traffic monitoring, achieves only 1 / 800 of the coverage performance of the TerraSAR-X (TS-X) satellite (please see Table 1) [5]. A future air borne SAR on a Gulfstream G550 "business" jet may reach already 1 / 60 of the performance of the TS-X. When comparing these numbers it has to be kept in mind that the aircrafts are not by that factor cheaper than the satellite!

	TerraSAR-X StripMap Mode	**DO-228** with E-SAR	**Gulfstream G-550** with new SAR
Speed	7.000 m/s	90 m/s	290 m/s
Swath Width	30 km	3 km	12 km
Coverage	**210 km²/s**	**0,27 km²/s**	**3,48 km²/s**

Table 1 Coverage performance of satellite versus aircraft

However, satellites are only justified if the global aspect is of importance, because the temporal coverage using only one satellite is extremely weak for a certain area! Typically it can take about one day until the satellite reaches the same area again and can take another snapshot of the scene. The use of geostationary satellites is impossible with currently available sensors, because in an altitude of 36.000 km the distance to the ground is too large. A high temporal coverage of let say 15 minutes can only be reached with a formation of satellites in the order of at least 40 units. But this number is not too high if it is taken into account that countries like Italy, Canada and Germany each plan to have a fleet of five to six SAR satellites in operation within the next years.

First Results with TerraSAR-X

In a research project initiated by the Transportation Research branch of DLR the German TerraSAR-X satellite shall be used to demonstrate the new application. Beside its high spatial resolution and radar beam steering capability another great advancement of the TS-X satellite is that it includes already a simple mode for the detection and measurement of moving objects and is therefore suitable for a first demonstration of space borne traffic monitoring [6,7,8]. It is a two-channel mode which allows for Along Track Interferomety (ATI) as well as Displaced Phased Centre Array (DPCA) signal processing techniques. It is possible to use a true two-channel mode with two receiver chains, called Dual Receive Antenna (DRA) Mode [9] and the so called Aperture Switching (AS) Mode which uses only one receiving chain, but a doubled PRF together with a toggled antenna weighting [10,11].

First experiments were carried out in the course of the sensor calibration and validation and ground segment check out activities during the early commissioning phase of TS-X. The analysis of two data sets was aimed at the verification of the SAR processor with moving targets and the commanding of the Aperture Switching mode. Figure 1 shows a small section of a single-channel TS-X strip map image of Lake Wörthsee near Oberpfaffenhofen, Germany. Two test cars equipped with Luneberg reflectors on the roof as well as GPS receivers were driven one after the other on a lakeside road, which was running more or less perpendicular to the satellite flight track. Due to the "train off the track effect" the radar signatures of the cars appeared displaced over the nearby lake. After SAR processing of the data, the GPS tracks of the cars were mapped into radar image, and from their line of sight (los) velocity the displacement in azimuth direction was predicted and marked in the image with two red squares. The two cars (T_1 and T_2) have been color coded according to their GPS speed. The two radar signatures of the cars are clearly visible at the predicted displaced image positions over the lake. Car T_2 was driving slightly faster than car T_1 and thus the displacement of T_2 is larger than the one of T_1. This example shows also the high sensitivity of the displacement effect. If the moving target can be detected and the road track where it was moving it is known, then the speed of the object can be determined with high accuracy.

Akquisition: TS-X Strip Map Mode

Date: 02.07.2007

Site: Wörthsee / Germany

Moving Target Analysis:

Azimuth displacement	T_1:	278 pixel
	T_2:	340 pixel
Beam velocity on ground	v_b	7010 m/s
Slant range distance	R_0	783 km
Vlos T_1:		19.5 km/h
Vlos T_2:		23.9 km/h
Vroad T_1:		29.8 km/h
Vroad T_2:		32.7 km/h

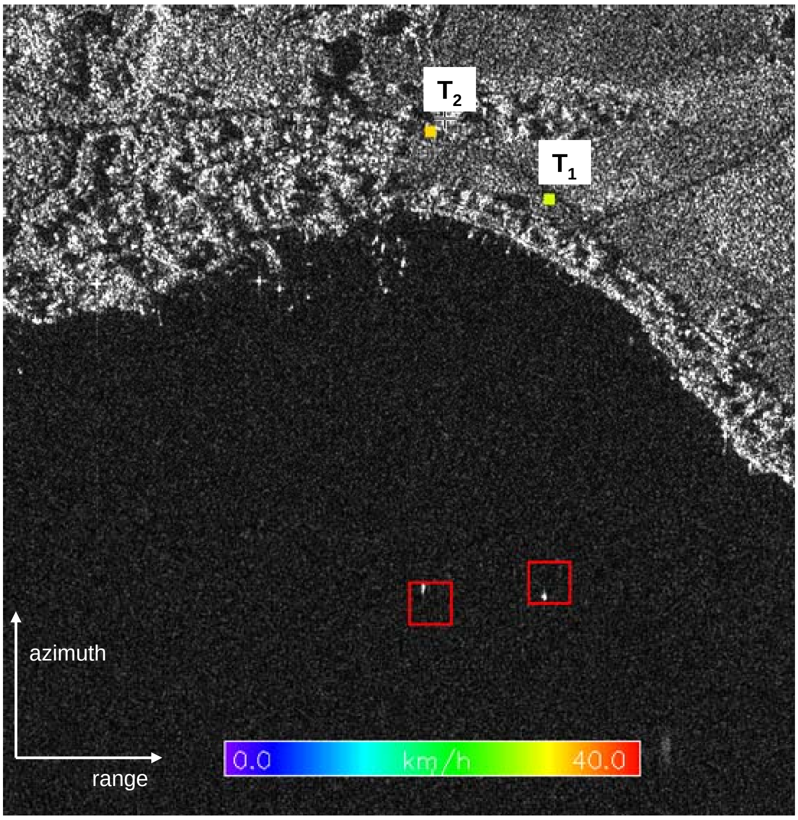

Fig. 1 Analysis of two moving objects in a TS-X strip map scene

A first data take in Aperture Switching Mode was acquired in the morning of June 27, 2007 over the motorway E45 (Autostrada del Sole) between Rome and Naples near Cassino, Italy. It served as a checkout for the commanding of the AS mode and was the first time that the aperture switching technique was applied with a space borne SAR sensor. Ground truth data were gathered during the data acquisition. Two video cameras which were mounted on a bridge over the motorway recorded the traffic flow. The film gives clues about the traffic density. A floating car tried to "float" together with the truck traffic and reached an average velocity of around 86 km/h.
After SAR processing of the scene, a co-registration of the two SAR images was carried out. Furthermore a subtraction as well as complex conjugate multiplication of the two images was performed in order to create the DPCA and the ATI interferogram image respectively. The effective ATI baseline was estimated from the mutual shift between the two channels. The stationary background ("clutter") was canceled out in the DPCA image and principally the signatures of only moving objects remained. The ATI phase was around zero, except for the moving target signatures also visible in the DPCA image.
The traffic processor which was used for this first attempt has been described in [6]. It base on the incorporation of a priori knowledge in form of the road network into the detection and measurement process. The initial detection of moving objects was carried out on the DPCA image. Then, two velocity estimates for each detected target, one based on the azimuth displacement and the other one on the ATI phase, were obtained. Afterwards a consistency check based on the estimated velocities and headings as well as on the road direction was carried out. Targets with an ATI phase of less than 0.5 rad were discarded in this first trial.
Figure 2 shows the first results of the automatic detection process. The moving objects found are overlaid on the SAR amplitude image at their displaced, i.e. their initially detected positions (red squares). They are furthermore color-coded according to their measured velocity at their estimated true position. A total of 38 vehicles were automatically found, 23 moving westbound and 15 eastbound. The velocities for both directions show their highest incidence slightly above 80 km/h, which corresponds very well with the ground truth observations for trucks.

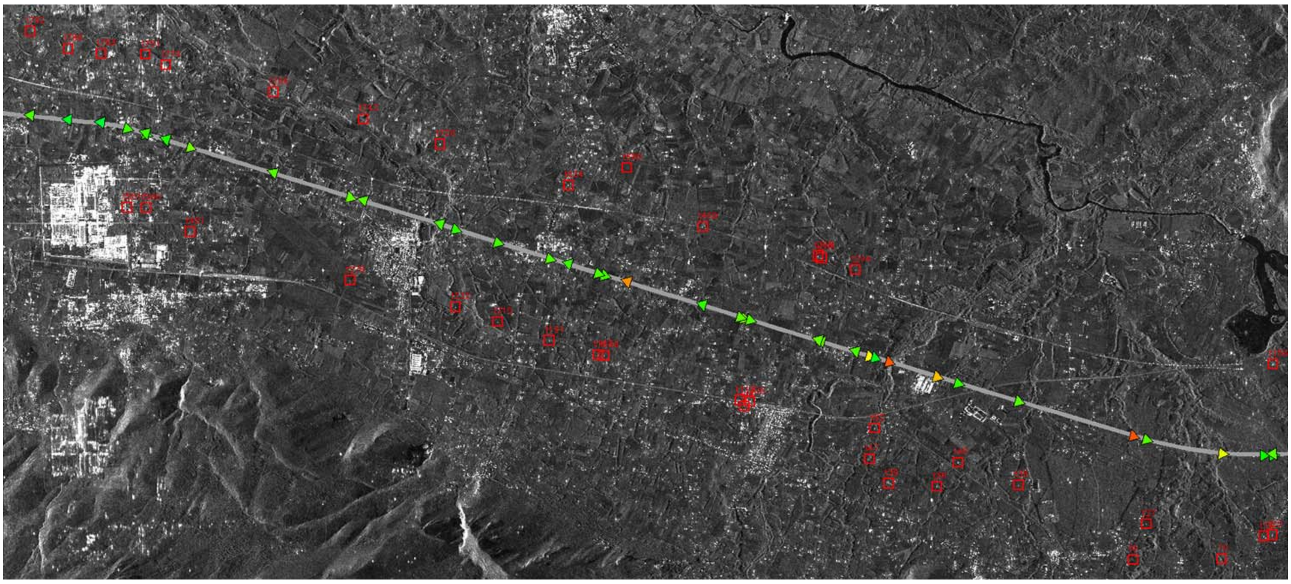

Fig.2 Automatic detection of moving objects on the E45 motorway near Cassino, Italy
(TS-X Strip Map Mode with Aperture Switching)

Please note that this first trial was carried out with sub-optimal conditions, since (1) an adaptive focusing of the potential moving targets was not applied, (2) due to the use of the AS mode (instead of the DRA-Mode), the PRF per channel was limited to a fairly small value of 2910 Hz and (3) the processing parameters have not yet been fine-tuned.

Conclusion

SAR satellites can become a good tool to gather traffic information where no ground installations are available. Although the TS-X satellite has not been specially designed for this purpose it will act as a starting point for the new application of traffic monitoring. The very first results of the TS-X commissioning phase include already a traffic measurement on a motorway in Italy. The derived average speed of trucks corresponds very well with ground truth observations.

Acknowledgement

We like to thank the System Engineering and Calibration (SEC) team for the planning, commanding and acquisition of the two data sets and for the development of the concept to realize the Aperture Switching Mode for TS-X.

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