Detection of traffic congestion in airborne SAR imagery

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Abstract

Detection of traffic congestion is an important issue both for the transportation research community and everyday life of the motorists. Remote sensing sensors installed on aircrafts or satellites enable information collection for various traffic applications over large areas. Optical systems are already in use but are limited due to their daylight operation and cloud-free conditions requirements. Synthetic aperture radar (SAR) systems seem to be more promising due to their all-weather capability. We approach the traffic congestion detection problem with a two-channel SAR airborne sensor flying in along-track (ATI) the motorway by combining various techniques: look processing, channel balancing, coherent difference, e.g. displaced phase center array (DPCA), image processing and incorporation of a priori information such as traffic flow model and road network. The potential of the proposed method is demonstrated with airborne E-SAR data collected during the flight campaign over a highway near Munich.

Introduction

During the past years, increasing traffic appears to be one of the major problems in urban and sub-urban areas [1]. Thus traffic monitoring aiming at the increase of transport safety and efficiency, on one side, and reduction of air and noise pollution, on the other side, has evolved to an important research issue. Traffic congestion and jams are one of the main reasons for immensely increasing transportation costs due to the wasted time and extra fuel.

Remote sensing sensors installed on aircrafts or satellites enable information collection on a large scale and thus seem to be very suitable for various traffic monitoring applications. Optical systems are already in use, e.g. [2], but are quite limited due to their daylight operation and cloud-free conditions requirements and the need of operator interaction during the data processing. Synthetic aperture radar (SAR) sensors due to their all-weather capabilities seem to be well suited for such type of applications. Ground moving target indication (GMTI) approaches based on the DPCA technique are currently under investigation [3, 4], but still suffer on the low vehicle detection rate, sometimes below than 10%. Such low detection rates make it difficult to derive reliable information about the traffic flow parameters, e.g. vehicle density.

We approach the traffic congestion detection in along-track two-channel SAR imagery in a different way. We don’t try to detect each individual vehicle and then to estimate its velocity, but instead of that we model a traffic flow on the road segment and thus derive directly the required traffic parameters from the data. Moreover, we show that the DPCA technique is not only useful for the detection of moving targets in the range direction, but in the azimuth direction too. A special advantage of the new method is that the sensor can fly along the motorway. Other methods which base on the ATI-phase or the "train off the track" effect require a flight track with a heading more or less across the road. This restriction is especially undesirable for airborne SAR systems because of their narrow swath width.

To confirm our idea and to validate the method some flight campaigns with the airborne experimental SAR sensor E-SAR of

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the German Aerospace Center (DLR) were performed during the recent years. The system allows a dual receive antenna (DRA) mode, and thus the acquisition of two, high resolution SAR images of the same scene within a short time lag between the two acquisitions. Practical results are presented showing the potential of the proposed method for the detection of traffic congestion on highways in along-track scenes.

Data

The DLR airborne experimental radar sensor E-SAR was used during the flight campaigns for the acquisition of the radar image data. This system has been in use for different applications and has been continuously improved and extended over a period of more than 16 years. It is operated on a Do-228 aircraft. Detailed description of the sensor can be found in [5]. Table 1 lists the main E-SAR system, flight and processing parameters used for the SAR experiments. Detailed description of the flight campaigns is given in the experimental part of the paper.

Table 1. E-SAR system and experiment parameters.

Parameter	Value
date of flight campaign	12.05.2005
frequency band	X (9.6 GHz)
polarization	VV
range bandwidth	100 MHz
pulse repetition frequency	1000 Hz
sensor forward velocity	89 m/s
altitude above MSL	4584 m
incidence angle	20 – 60 deg
resolution (rg x az)	2 m x 0.085 m
SLC pixel spacing (rg x az)	1.5 m x 0.089 m
number of looks	21
look bandwidth	52 Hz
look overlap	about 20 %
look beam width angle	0.35º

Methodology

Our approach to the traffic congestion detection in along-track two-channel SAR airborne imagery is based on the combination of various techniques: look processing, channel balancing, coherent difference, e.g. displaced phase center array (DPCA), image processing and incorporation of a priori information such as traffic flow model and road network.

The large synthetic aperture length or beam width angle of approximately 7º of the airborne radar sensor E-SAR can be divided into several looks (sub-apertures), thus decreasing the target's illumination time or equivalently the spatial resolution in azimuth direction. Due to a very high resolution in azimuth, e.g. 8.5 centimeters for X-band, it is even desirable to reduce this resolution in order to achieve approximately quadratic ground pixels. In the subsequent experiments the following setup was used (see Table 1). The whole processing bandwidth in azimuth was divided into 21 looks resulting in a look bandwidth of 52Hz which allowed us to obtain approximately the beam width angle or aspect angle resolution of 0.35º and an overlapping of looks about 20%.

The DPCA technique is based on the coherent difference of the two complex focused SAR images. DPCA is mostly used for the detection of moving targets in the range direction. In this paper we show that DPCA can be useful for the detection of targets moving in the azimuth direction too. Pre-processing of SAR data, such as channel balancing are of great importance for the successful and stable results of DPCA. Two properties of the DPCA technique support the detection of vehicles in a great extent. First, it suppresses the clutter and strong stationary targets in the SAR image. Secondly, it enhances the moving target signature due to the change of the phase center and/or amplitude in the resolution cell.

Image processing techniques can be applied to derive the vehicle density in the binarized DPCA image. This estimated vehicle density can be related to the theoretical vehicle density, which can be acquired by modelling the traffic flow for a road segment. This model is derived from a priori information about the vehicle sizes and road parameters [6] and the road network, e.g. NAVTEQ road data base [7]. This modelled vehicle density is directly related to the average vehicle velocity on the road segment and thus the information about the congestion can be derived.

One of the extreme cases is the completely stopped traffic when the distance between the vehicles is in the range of few meters. In this case the jam can be detected directly in the amplitude SAR image. If the road diverges from the satellite flight direction moving targets will be displaced in the azimuth direction. In this case the offset can be used to determine the velocity of the moving objects.

Experiment

The experimental data in X-VV have been collected by the DLR airborne E-SAR sensor during a flight campaign on May 12th, 2005 over the A96 highway between Gilching and Germering, near Munich, South Germany. The footprint of the SAR data take is shown in Fig. 1.

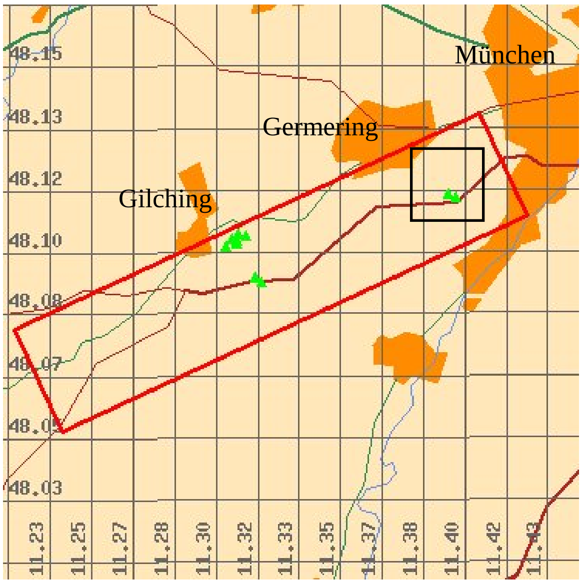

Fig. 1. The footprint of the SAR data take acquired during the flight campaign on May 12, 2005 over the A96 highway between Gilching and Germering, near Munich, South Germany. The longer side of the footprint is in parallel to the flight direction. The analyzed area is marked as a square.

Reference optical data were collected simultaneously with SAR data by the DLR 3K digital camera system [8], which was installed on the same aircraft.

An example for the traffic congestion detection is presented in Fig. 2. We can observe the congestion on the highway (left to right direction) in the optical reference mosaic image (Fig. 2a). The average velocity estimated in the reference data was between 0 to 40 km/h [2]. As expected, the congestion is not observed in the single channel SAR amplitude image (Fig. 2b). In the DPCA image (Fig. 2c) the congestion can be identified very easily, especially on the road segments parallel to the flight direction. For road segments deviating from this ideal direction the vehicles are displaced slightly in azimuth direction and exhibit a reduced radar cross section due to the “unfavourable” aspect angle [9, 10]. The estimated velocity profile from the DPCA image (Fig. 2d) corresponds quite well with the reference measurements for most road segments and the congested area is detected correctly.

Discussion

The detection of moving objects with the DPCA method was so far applied to objects moving in the radial direction of the radar (in "across track"). Here the phase sensitivity for objects moving towards or away from the sensor is very high, because movements of fraction of a wavelength (in the mm-range) do already cause a detectable phase change. If in contrast an object moves in parallel to the sensor flight track no change in distance appears and at first glance no phase change can be detected with the DPCA method. However, the phase of the image pixel of the front and the back of a moving object do change, if the time lag between the capture of the two images and the spatial resolution of the radar is large enough! The pixel which lies in front of the moving object at the first image capture contains the phase of the background scene. At the time of the second image capture the object will have moved and this pixel is dominated now with the phase of the moving object. A similar phenomenon occurs at the back of the moving object: the pixel which covers the back of the object in the first image will contain the information of the shadow region of the second image.

Due to the high flight velocity of a satellite the distance between the two antennas which capture the first and the second image must be quite high in order to achieve similar conditions like in the described airborne case. Ideal will be a tandem configuration of two satellites with a distance in between in the order of 100m. With even larger "along-track baselines" and high spatial image resolution it might even be possible to determine the speed of the object by the mismatch of the moving object in the two images. Further advantage of this configuration is that each satellite can be operated in a standard single channel mode. We are looking forward to the first data of the TanDEM-X project to prove this idea [11].

Conclusion

We have proposed the traffic congestion detection method in along-track two-channel SAR imagery based on the combination of various techniques such as look processing, DPCA and image processing and using the following a priori information: traffic flow model and road network.

The potential of the proposed method for traffic monitoring applications is demonstrated for airborne E-SAR data collected during various flight campaigns.

Of course, the method is not limited to only airborne sensors. It can be applied to dual receive antenna satellites such as TerraSAR-X [12, 13] and Radarsat-2 or a tandem formation of satellites, e.g. TerraSAR-X and a planned satellite TanDEM-X.

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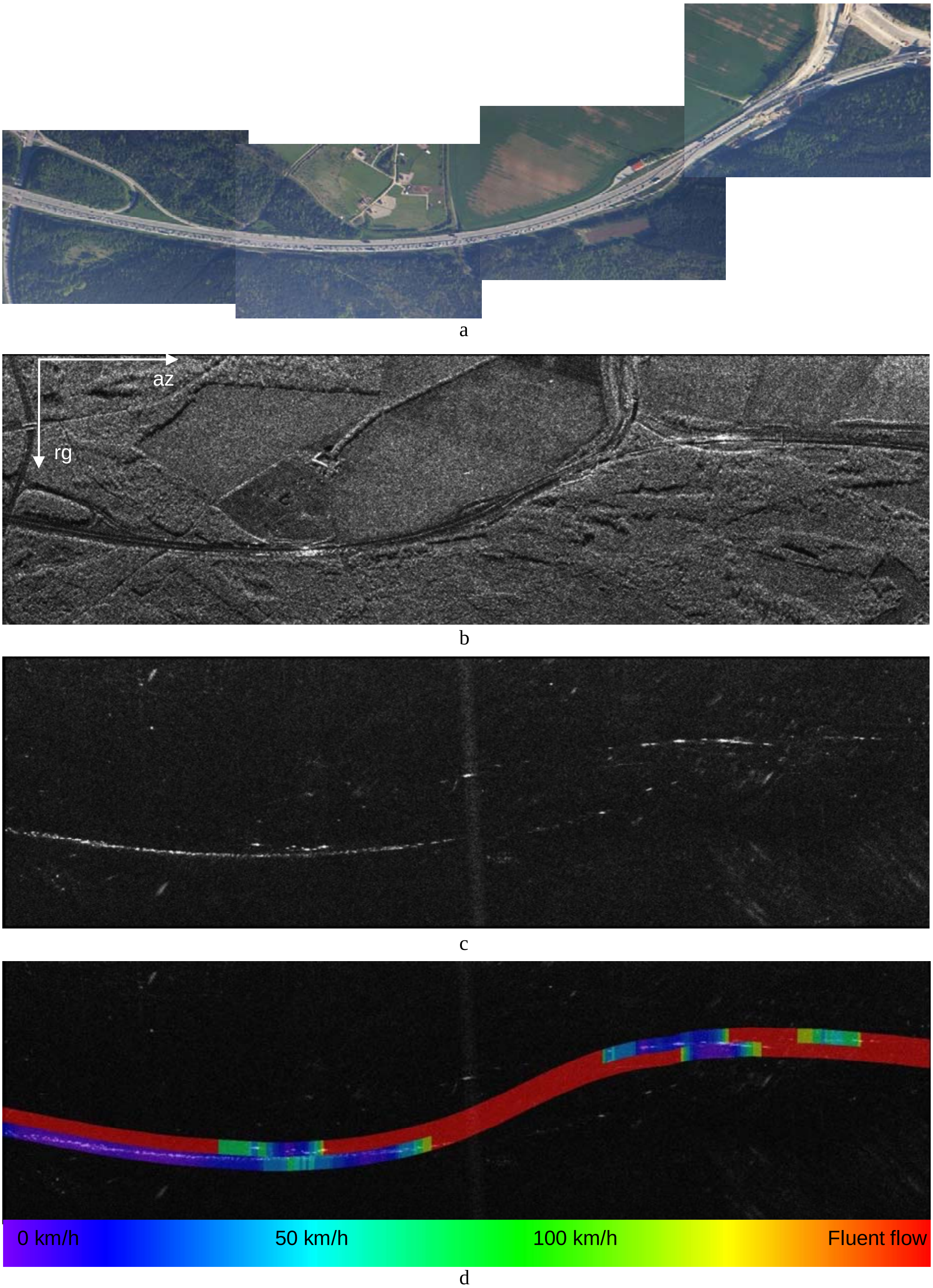

Fig. 2. The reference digital camera mosaic image of a part of highway between Germering and Munich, South Germany (a), E-SAR one channel amplitude image (b), DPCA image (c) and resultant velocity profile image (d).