TRAFFIC CONGESTION PARAMETER ESTIMATION IN TIME SERIES OF AIRBORNE OPTICAL REMOTE SENSING IMAGES

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ABSTRACT

In this paper we propose a new model based traffic parameter estimation approach in congested situations in time series of airborne optical remote sensing data. The proposed approach is based on the combination of various techniques: change detection, image processing and incorporation of a priori information such as road network, information about vehicles and roads and finally a traffic model. The change detection in two images with a short time lag of several seconds is implemented using the multivariate alteration detection method resulting in a change image where the moving vehicles on the roads are highlighted. Further, image processing techniques are applied to derive the vehicle density in the binarized change image. Finally, this estimated vehicle density is related to the vehicle density, acquired by modelling the traffic flow for a road segment. The model is derived from a priori information about the vehicle sizes and road parameters, the road network and the spacing between the vehicles. Then, the modelled vehicle density is directly related to the average vehicle velocity on the road segment and thus the information about the traffic situation can be derived. To confirm our idea and to validate the method several flight campaigns with the DLR airborne experimental wide angle optical 3K digital camera system operated on a Do-228 aircraft were performed. Experiments are performed to analyse the performance of the proposed traffic parameter estimation method for highways and main streets in the cities. The estimated velocity profiles coincide qualitatively and quantitatively quite well with the reference measurements.

1. INTRODUCTION

During the past years, increasing traffic appears to be one of the major problems in urban and sub-urban areas. Traffic congestion and jams are one of the main reasons for immensely increasing transportation costs due to the wasted time and extra fuel. Conventional stationary ground measurement systems such as inductive loops, radar sensors or terrestrial cameras are able to deliver precise traffic data punctually with high temporal resolution, but their spatial distribution is still limited to selected motorways or main roads.

A new type of information is needed for a more efficient use of road networks. Remote sensing sensors installed on aircrafts or satellites enable data collection on a large scale thus allowing wide-area traffic monitoring. 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 approaches based on the Displaced Phase Center Arrays technique are currently under investigation for airborne SAR sensors and space borne satellites, e.g. TerraSAR-X, but still suffer from the low vehicle detection rate, quite often below 30% (Meyer 2007). Traffic monitoring from optical satellites is still limited due to the not sufficiently high spatial resolution, but the detection of vehicle queues seems to be promising (Leitloff 2006). As it is shown already in (Reinartz 2006, Hinz 2008) airborne optical remote sensing technology has a great potential in traffic monitoring applications. Several airborne optical remote sensing systems are already in experimental use at the German Aerospace Center DLR, e.g. airborne 3K camera system, consisting of three digital cameras capable of acquiring three images per second (Kurz 2007), and LUMOS (Ernst 2003). Automatic detection of vehicles and estimation of their velocities in sequences of optical images is still a challenge. Most known approaches are image based and still result in a too low completeness (e.g. less than 70%) thus being not yet suitable e.g. for the estimating of the traffic density and flow (Rosenbaum 2008).

In this paper we propose a new model based approach and investigate its potential for the traffic parameter estimation in congested situations in sequences of airborne optical remote sensing data. Instead of detecting each individual vehicle and then estimating its velocity (microscopic model) as e.g. in (Rosenbaum 2008) we exploit a linear vehicle density-speed relationship for a road segment (macroscopic model) to derive vehicle velocities from the estimated vehicle densities in an image.

The paper is organized as follows: first, the proposed method is described in the Section 2, then, the results of experiments and discussions are presented in Section 3, followed by conclusions and references.

2. APPROACH

Our approach for the traffic parameter estimation in sequences of optical images is based on the modelling of traffic flow on the road segments and thus allows the direct derivation of the required traffic parameters from the data, such as the vehicle density and average velocity. Further, other traffic information, like the existence of congestion, the beginning and end of congestion, the length of congestion, actual travel times, and so on can be easily extracted. The proposed method is based on the combination of various techniques: change detection, image processing and incorporation of a priori information such as road network, information about vehicles and roads and finally a traffic model. The change detection in two images with a short time lag is implemented using the Multivariate alteration

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detection (MAD) method (Nielsen 2007) resulting in a change image where the moving vehicles on the roads are highlighted. Image processing techniques can be applied to derive the vehicle density in the binarized change image. This estimated vehicle density can be related to the vehicle density, acquired by modelling the traffic flow for a road segment. The model is derived from a priori information about the vehicle sizes and road parameters, the road network and the spacing between the vehicles.

2.1 Congested traffic model

Numerous investigations on real traffic data show that under congested conditions the following assumption is true: a class of vehicle's spacing is a linear function of the speed of all vehicles

$$S_i = B_i \cdot g(v) + L_i \,, \tag{1}$$

where spacing S_i is the front-to-front vehicle distance in meter, B_i is a dimensionless parameter of the model, function *g(v)* transforms velocity (km/h) into meters, e.g. *g*(100 km/h) = 100 m, L_i is the vehicle length in meter and *i* is the vehicle class, e.g. passenger car or truck. Parameter *B* can be interpreted in the following way: for *B=0.5* and *L=0* the formula (1) means for all drivers a well-known rule of thumb "safe distance = half speedometer reading in metres". As already mentioned this model well describes a congested traffic. The *B* value is ranging normally between 0.5 and 1.0 (for more details see (Palubinskas 2009)).
Now the traffic density can be calculated as

$$D(\#vehicles\ per\ km) = \frac{1km}{S}\,, \tag{2}$$

where $S = \sum_i p_i \cdot S_i$, p_i is a proportion of vehicle class *i* and $\sum_i p_i = 1$. Thus for density calculation in (2) the weighted mean value of vehicle spacings is used.
The modelled vehicle density is directly related to the average vehicle velocity on the road segment and thus the information about the traffic situation can be derived. The flow diagram of the proposed method is shown in Fig. 1.

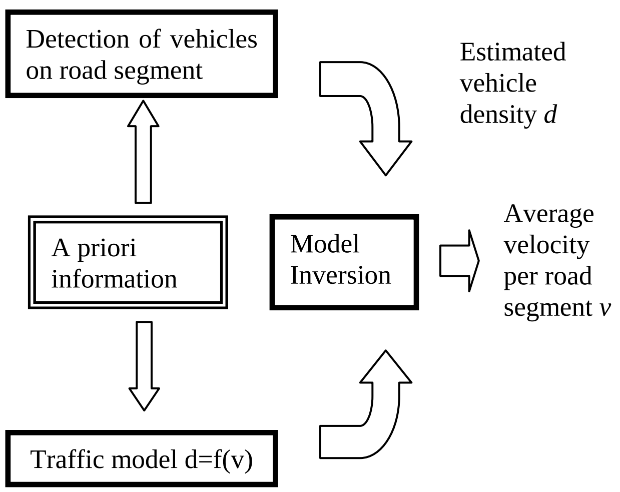

Figure 1. Flow diagram of the proposed traffic parameter extraction method

Detailed description of the proposed method is provided in (Palubinskas 2009).

3. EXPERIMENTS

To confirm our idea and to validate the method several flight campaigns with the DLR airborne experimental wide angle optical 3K digital camera system operated on a Do-228 aircraft were performed. In this paper one of such experiments is presented. Since the area covered is quite large, the evaluation is performed for many road segments and can therefore be regarded as representative measures.

3.1 DLR 3K camera system

The 3K camera system ("3 Kopf" = "3 head") consists of three non-metric off-the-shelf cameras (Canon EOS 1Ds Mark II, 16 MPixel). The cameras are arranged in a mount with one camera looking in nadir direction and two in oblique sideward direction, which leads to an increased FOV of max 110°/ 31° in across track/flight direction. The camera system is coupled to a GPS/IMU navigation system, which enables the direct geo-referencing of the 3K optical images. Based on the use of 50 mm Canon lenses, the pixel size at a flight height of 1000 m above ground is 15 cm and the image array covers 2.8 km in width. The pixel size increases up to 50 cm and the swath width up to 8 km for a flight height of 3 km.

3.2 Test site and data

The motorway A8 south of Munich is one of the busiest parts of the German motorway network with an average load of around 100.000 vehicles per day. Test site was a 16 km motorway section between motorway junctions "Hofolding" and "Weyarn". On 2nd Sep. 2006, heavy traffic was expected at this section caused by homebound travellers in the direction of Munich. Three 3K data takes were acquired between 14:01 and 15:11 from 2000m above ground in three over flights. During each over flight, 22 image bursts were acquired each containing four consecutive images. The time difference within these bursts was 0.7 s, so that each car was monitored at least for 2.1 s. To collect the reference data each lane was manually processed, that means all vehicles were detected in the images by visual interpretation and their velocities measured.

3.3 Estimation of traffic model parameter *B*

The unknown model parameter *B* (under assumption of a mean vehicle length of 4.7 m for passenger cars) was analyzed for each lane and direction separately thus resulting in a total evaluation length of 153 km. Due to the time of image acquisition on Saturday afternoon there were very few trucks in this part of the road so their influence was neglected. The estimated values for the traffic model parameter *B* are plotted in Fig. 2 separately for the right and left lanes for the three lane road. The analysis resulted in an average *B* = 0.76 (with standard deviation (STD) equal 0.38) for the left lane and the average *B* = 1.18 (STD = 0.88) for the right lane and total B is approximately equal to 1 (STD = 0.63). From Fig. 2 it can be deduced that a constant value for *B* can be assumed except for very low velocities under 5 km/h (in this case the outliers from our model are most probable but are insignificant because of the usage of other approaches (Palubinskas 2009)). Parameter values for the low density traffic must be treated very carefully because our model is designed for the congested traffic. For free flow traffic the values for *B* can be larger.

3.4 Traffic parameter extraction

Results of the traffic parameter extraction on the test site are shown in Fig. 4. In this figure, (a) is the original mosaic image with reference velocity measurements plotted. It is divided into four parts marked in blue coloured frames. These image frames are displayed from left to right in the following figures (b-e): the original image (upper image) and velocity profiles for separate road directions plotted on the change detection image (lower image).

Traffic congestion is defined usually using the average velocity or the traffic density. Unfortunately, there is no unique definition and it is usually country dependent. Having the average vehicle velocity for each road segment the congestion detection is a trivial task and can be performed by a simple threshold. For example, if the congestion is defined for velocities up to 50 km/h, then the red coloured areas in Fig. 4 can be interpreted as congested ones.

For the quantitative interpretation velocity profiles estimated with our approach are compared graphically to the reference measurements in Fig. 3.

3.5 Discussions

First we would like to note some interesting observations when analyzing the curves in Fig 3. The maximal velocity was limited to 120 km/h for free flow traffic, but nevertheless we can see that our model, though optimal for congested conditions, can capture the right velocity (see parts of the blue curve from 2200 m to 2700 m) because of the presence of some trucks in the images.

The overestimation of the velocity in some stages of congestion (parts between 4000 m - 4300 m and 6000 m - 6200 m) can be explained by the behaviour of the drivers who decelerate just before the congestion and thus increase the spacing. The same effect occurs after end of congestion when the drivers begin to accelerate (part between 5400 m and 5500 m). Moreover, halting vehicles are distorting the estimation additionally.

By setting the velocity threshold e.g. to 50 km/h we detect two congested areas (4300-5300 and 5800-6400). Further we could easily extract the following parameters: the beginning and end of congestion, length of congestion and travel times.

The performance of the proposed method is very dependent on the good quality of the geo-referencing of overlapping images and the quality of the road data base.

A priori information concerning vehicle and road parameters should be adapted very carefully to the regional traffic conditions.

For the accurate vehicle density estimation the time lag between the two image acquisitions should be selected according to the constraints presented in the paper.

Image based methods (microscopic model) perform normally better for a higher resolution (less than 30 cm pixel spacing (Rosenbaum 2008)), thus the aircraft flight height should be low or equivalently one should take into account the reduced image coverage. It seems that the proposed model based method is not very sensitive to the resolution because it is working on the macroscopic model level.

To overcome the problem of halting vehicles the investigation of more sophisticated solutions, for example a combination with other methods, e.g. classification of a single image, is planned.

Further experiments are planned to test the approach for off-nadir scenes and in the cities during different environmental conditions.

Another research direction is aiming to derive other traffic parameters such as traffic density and traffic flow.

4. CONCLUSIONS

A new traffic congestion detection approach for image time series acquired by the airborne optical 3K camera system is introduced. It allows us to derive one of the main traffic parameters - the average velocity - and the vehicle density as an intermediate product. Other parameters such as the beginning and end of congestion, length of congestion and travel times could be derived easily on request. The method is based on the vehicle detection on the road segment by change detection of two images with a short time lag, usage of a priori information and a simple traffic model. Experimental results show the great potential of the proposed method for the extraction of traffic parameters on highways in along-track scenes. The estimated velocity profiles coincide qualitatively and quantitatively quite well with the reference measurements.

5. ACKNOWLEGMENT

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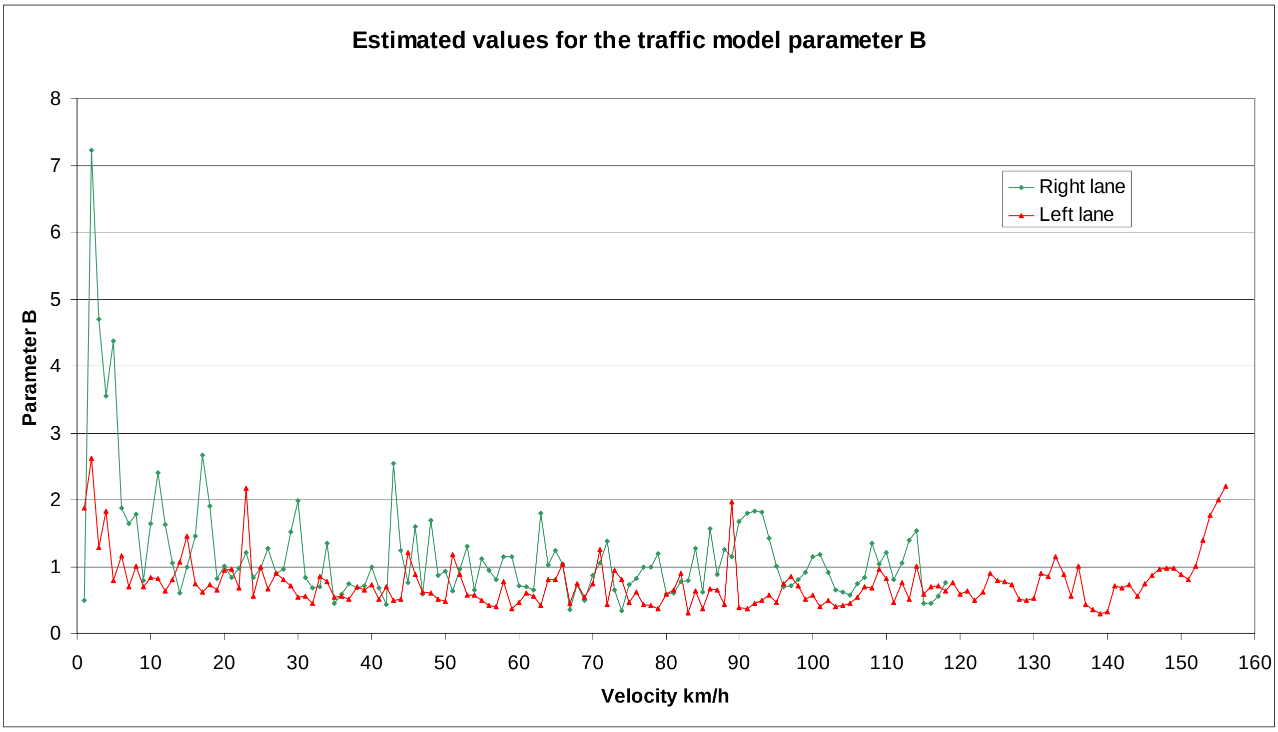

Figure 2. Estimated values for the traffic model parameter *B* for left and right lanes separately

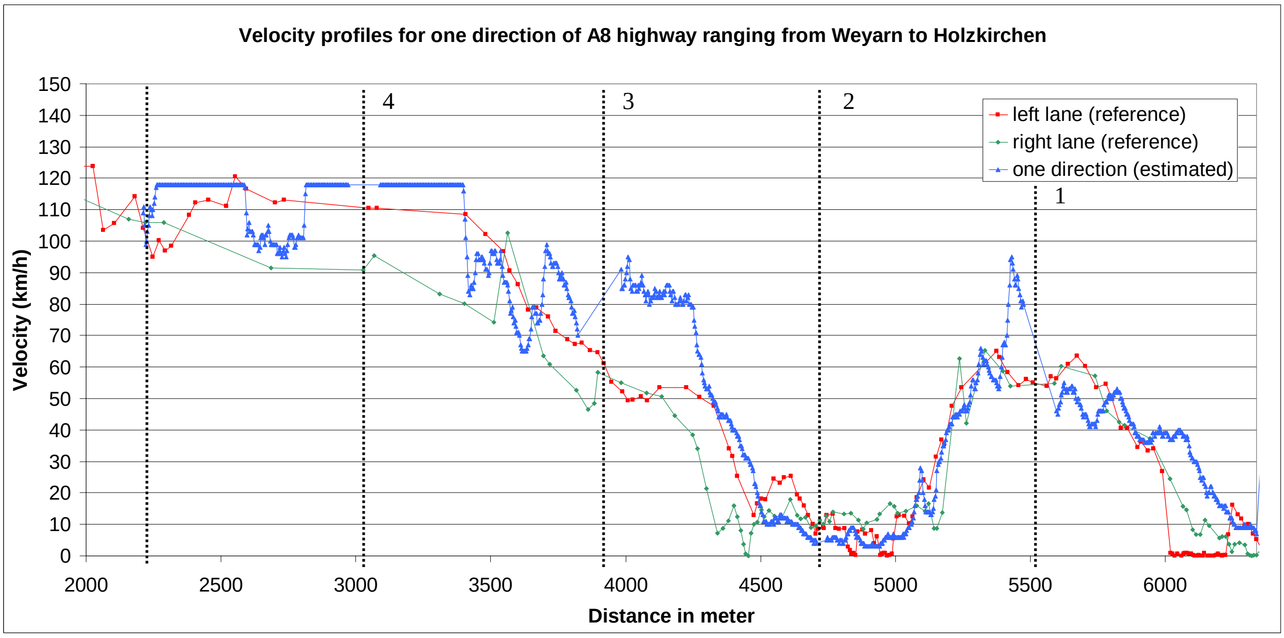

Figure 3. Velocity profiles estimated with the proposed approach (blue color) vs the reference measurements (red – left lane, green – right lane). Plot parts separated by dashed vertical lines (numbered) correspond to image parts shown in Fig. 4

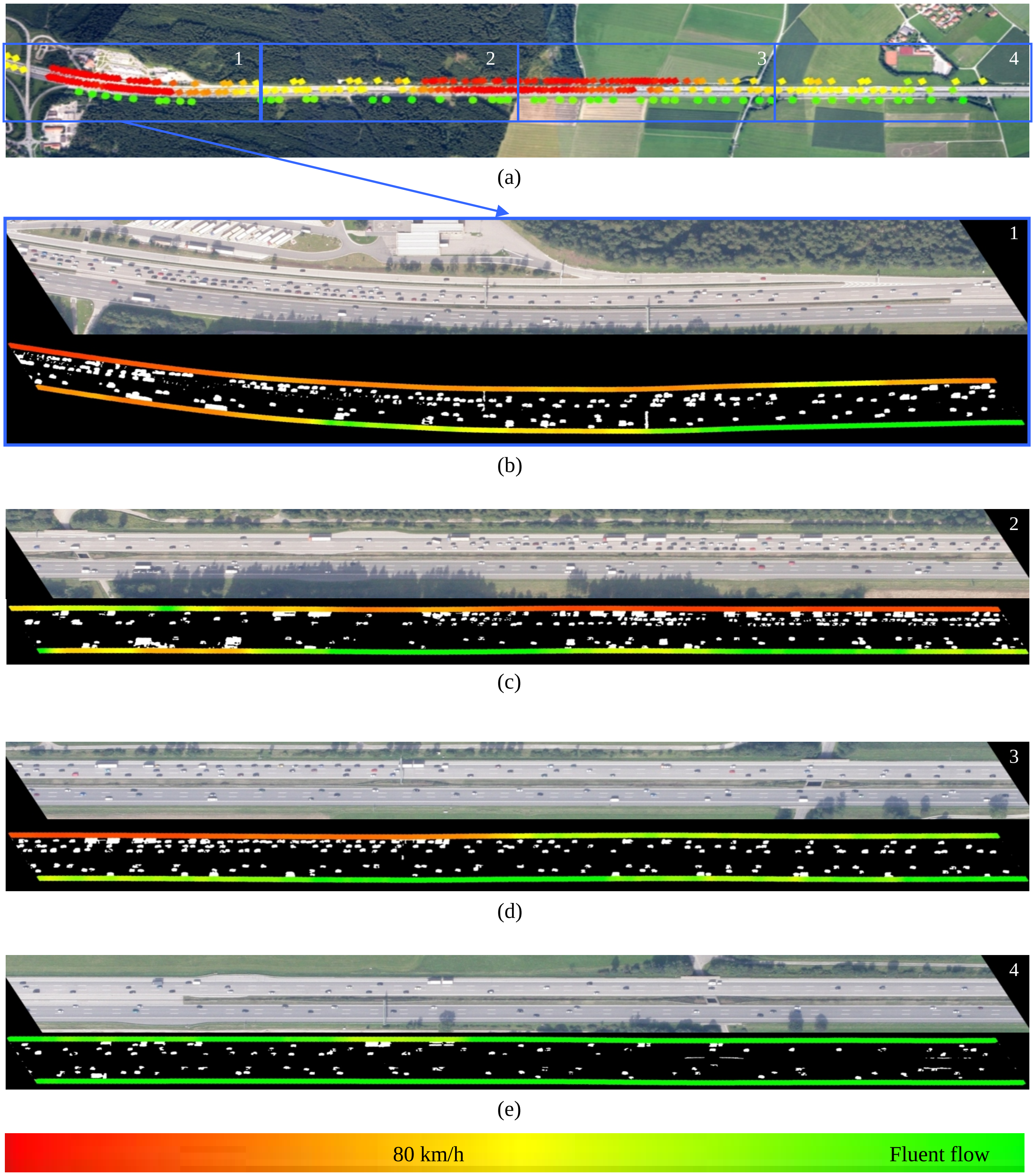

Figure 4. Example of the traffic congestion detection on A8 highway between Munich and Salzburg for 3K sensor data acquired during ADAC flight campaign on 2.9.2006: (a) the original mosaic image with reference velocity measurements plotted and (b-e) corresponding blue coloured frames of the original mosaic image (upper image) and velocity profiles for separate road directions plotted on the change detection image (lower image)