TRAFFIC CLASSIFICATION AND SPEED ESTIMATION IN TIME SERIES OF AIRBORNE OPTICAL REMOTE SENSING IMAGES

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ABSTRACT

In this paper we propose a new two level traffic parameter estimation approach based on traffic classification into three classes: free flow, congested and stopped traffic in image time series of airborne optical remote sensing data. The proposed method is based on the combination of various techniques: change detection in two images, image processing such as binarization and filtering and incorporation of a priori information such as road network, information about vehicles and roads and finally usage of traffic models. 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 and denoised 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 traffic classification, 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 speed 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 conducted. Experiments are carried out to analyse the performance of the proposed traffic parameter estimation method for highways and main streets in the cities. The estimated speed profiles coincide qualitatively and quantitatively 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 local traffic data 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 speeds 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 speed (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 speeds from the estimated vehicle densities in an image.

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

2. APPROACH

Our approach for traffic parameter estimation in sequences of optical images consists of a two level method (see Figure 1).

First, traffic classification is performed into three main classes: free flow, congested and stopped traffic. Then, for each traffic class, modelling of traffic flow on the road segments is performed separately allowing the direct derivation of the required traffic parameters from the data, such as the vehicle density and average speed. 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 (NAVTEQ), information about vehicles and roads and finally traffic models. The change detection in two images acquired with a short time lag (~ 2 sec) is implemented using the Multivariate Alteration 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 and denoised change image. This estimated vehicle density can be related to the real 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 (Palubinskas 2009, 2010).

2.1 Traffic classification

Traffic classification is performed in order to group vehicles on the road into three main classes: free flow, congested and stopped traffic. There exist already some approaches for this task based on a sequence of images (e.g. Zeller 2009). We did not found that they are superior to our proposed single image traffic classification which additionally allows direct derivation of approximate vehicle density and thus average speed for a road segment. First, a colour (RGB) image is transformed to a gray (intensity) image using YCbCr colour transformation (YCbCr 2010), which is believed to represent better the intensity of colour image then a simple mean. Then, the image is shifted in along road direction by a half of vehicle size and a difference of original intensity image and its shifted version is calculated (the roads are straightened before using NAVTEQ road database). Finally, a sum of absolute differences (SAD) is calculated for a road segment of a specified length. Simple thresholding technique can be applied to classify SAD values into three classes: low values correspond to free flow traffic, middle values - congested traffic and high values - stopped traffic. Additionally, binarized and denoised SAD image can be used to estimate roughly vehicle density d_c for a given road segment.

2.2 Traffic models

For each traffic class a different traffic model is applied in order to derive desired traffic parameters.

2.2.1 Congested traffic

Numerous investigations (e.g. Greensfield, 1935; Kockelmann, 1998) 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 speed (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 (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 spacing is used.
The modelled vehicle density D is directly related to the average vehicle speed on the road segment and thus the information about the traffic situation can be derived (see Figure 2). Detailed description of the proposed method is provided in (Palubinskas 2009).

2.2.2 Stopped traffic

For stopped vehicles, the previously introduced way of estimating vehicle density is no more valid: the values are significantly underestimated or even approaching zero due to the subtraction of vehicle blobs in a change image. Of course, the same model can be applied if vehicle density d_c estimated during the traffic classification level is used and thus a speed of very slowly moving vehicles can be estimated.

2.2.3 Free flow traffic

For free flow traffic a very simple model is used: that is a maximal allowed speed for a particular road segment is assumed thus again leading to a rough speed estimate.

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 these 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 approximately 15 cm and the image swath is 2.8 km. The pixel size increases up to 50 cm and the swath width up to 8 km for a flight height of 3 km. For more details see (Kurz 2007).

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 traffic volume of around 100.000 vehicles per day. The 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 speeds measured.

3.3 Traffic parameter extraction

Results of traffic parameter extraction on the test site are shown in Figures 3 and 4. In Figure 3 an overview of results are presented for the mosaic of five frames: highway section of approximately 4 km length. We see that the estimated speed profiles coincide quite well with the reference measurements. In Figure 4 speed estimation results are presented for each of five segments separately for more details.

Traffic congestion is defined usually using the average speed or the traffic density. Unfortunately, there is no unique definition because of different types of roads (highway, city streets) and moreover it is usually country dependent. Having the average vehicle speed 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 speed up to 50 km/h (for highways), then the red coloured areas in Figures 3 and 4 can be interpreted as congested ones.

Quantitative evaluation of speed profiles is presented in (Palubinskas 2009).

3.4 Discussions

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 (Palubinskas 2010).
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 swath. It seems that the proposed model based method is not very sensitive to the resolution because it is working on the macroscopic model level.

We would like to mention that possible false alarms may occur during traffic classification due to object shadows on the road (e.g. tree shadows as can be seen in Figure 4(d)). Because of the usage of only single images for traffic classification the following objects: objects (not vehicles) on or over the road (bridges, signs, constructions) or objects nearby the road (tree and house shadows on the roads) cannot be surely separated from vehicles. Further research is needed to incorporate more information (e.g. GIS, radar sensor data) in this level.

What concerns future work 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 at deriving other traffic parameters such as traffic density and traffic flow.

4. CONCLUSIONS

A new traffic classification and model-based 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 speed - and the vehicle density as an intermediate product. Other parameters such as the beginning and end of congestion, length of congestion and travel times can be derived easily from these results. The method is based on the vehicle detection on road segments by change detection of two images with a short time lag, usage of a priori information and simple traffic models. Experimental results show the great potential of the proposed method for the extraction of traffic parameters on highways in along-track scenes. The estimated speed profiles coincide qualitatively and quantitatively quite well with the reference measurements.

5. ACKNOWLEGMENT

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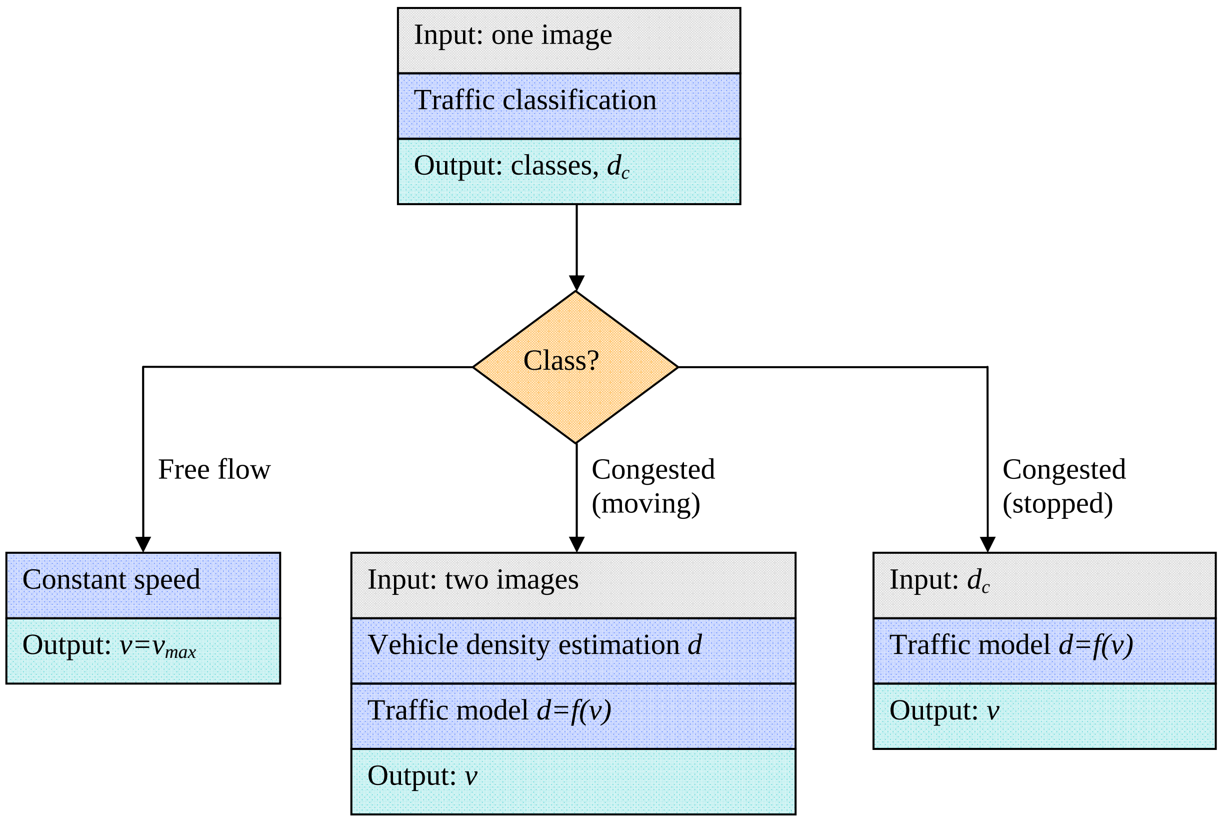

Figure 1. Two level concept for traffic classification and model-based speed estimation. Gray boxes mark input data for the following processing modules (blue boxes) and finally green boxes stand for output parameters.

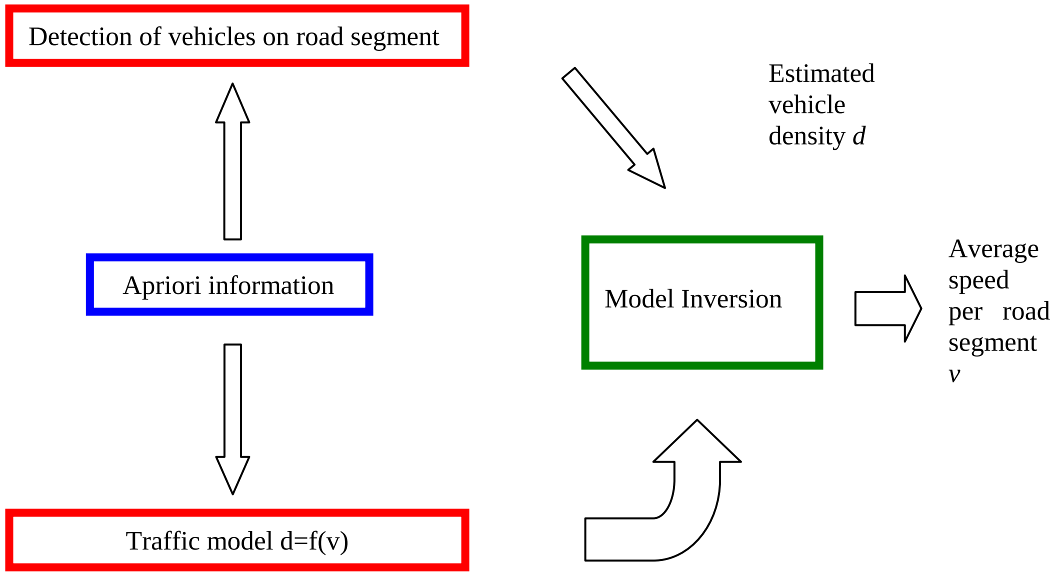

Figure 2. Flow diagram of the proposed traffic congestion detection method.

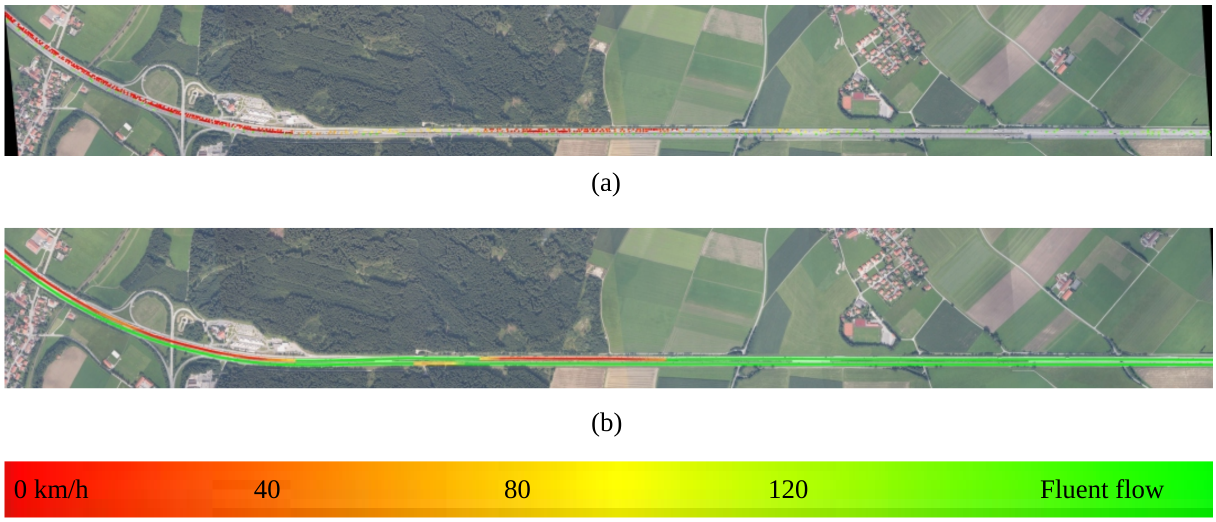

Figure 3. Overview of traffic congestion detection on A8 highway between Munich and Salzburg for 3K sensor data acquired during ADAC flight campaign on 2nd September 2006. Original mosaic of five frames is overlaid by speed profiles for separate road directions: (a) reference measurements and (b) estimated values (red colour stands for congested area and green - for free flow traffic).

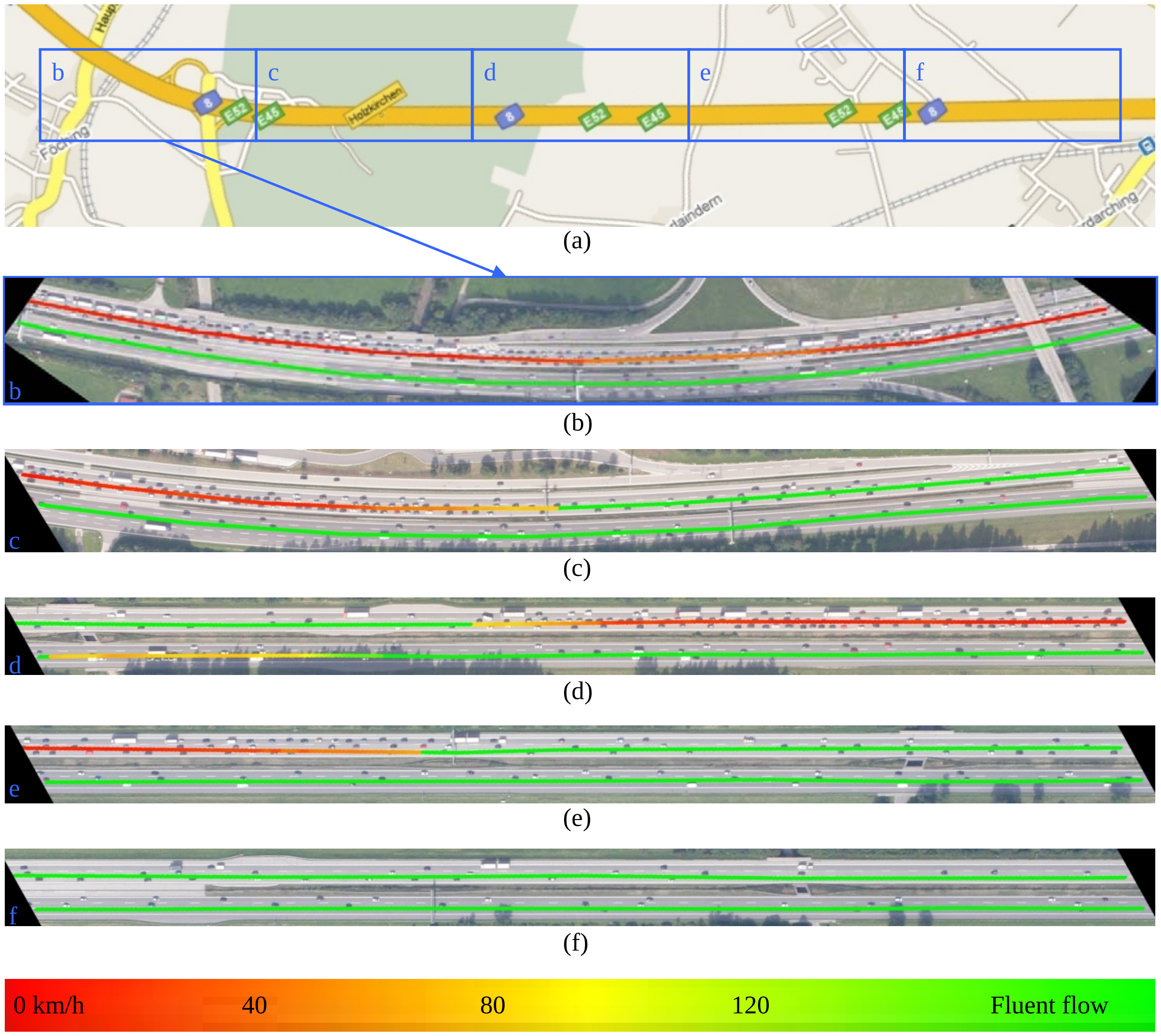

Figure 4. Detailed example of traffic congestion detection on A8 highway between Munich and Salzburg for 3K sensor data acquired during ADAC flight campaign on 2nd September 2006: (a) Google map with blue boxes showing the 5 acquired frames (from left to right) and (b-f) for each frame speed profiles for separate road directions plotted on the original 3K image (red colour stands for congested area and green - free flow traffic).