Video-based traffic state estimation on smart cameras for traffic information systems

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Abstract This paper presents an accurate and efficient traffic state detection system that is implemented on smart cameras. Our video analysis method employs feature tracking and edge information along with the camera calibration parameters for periodic level of service (LOS) measurements. After a calibration using the known lengths of lane markings, the smart cameras perform the LOS estimation onboard and report any change in the observed traffic state to a traffic information system. Architecture of the onboard system and video detection methods are introduced in this paper. Evaluation results indicate a detection precision of more than 95% for stationary traffic.

Keywords: video analysis, embedded computer vision, smart camera, traffic speed and density estimation, level of service classification

1. Introduction

Modern traffic information systems provide reliable traffic messages in real-time. Today, these traffic messages are generated from different data sources, such as drivers' reports, traffic sensors, or travel-times recorded by toll systems [**Fehler! Verweisquelle konnte nicht gefunden werden.**]. For many years, video surveillance has been used to recognize traffic jams, accidents, and other threats on the road. In 2011, ASFINAG (the Austrian motorways and expressways operator) has operated more than 4000 cameras to monitor the traffic state on the Austrian motorway and expressway network. In the current operational system of ASFINAG, the cameras are merely used for human inspection of videos. Automatic video analysis can be added to report interesting situations, such as traffic jams or weather-related road conditions, to human traffic operators.

In this paper we present an accurate traffic state detection system for motorways, which is implemented on smart cameras. Smart cameras [**Fehler! Verweisquelle konnte nicht**

gefunden werden.] integrate video sensing, video processing, and communication in a single device. In contrast to most other methods which rely on object detection and background modeling, our method uses robust feature statistics to estimate the mean speed and traffic density on smart cameras. The presented system has been developed as part of the research project SOMA-LOOK2 [**Fehler! Verweisquelle konnte nicht gefunden werden.**][5], which aims at increasing the quality of traffic messages using multimedia data and multi sensor fusion.

2. System description

2.1 Architecture and data flow

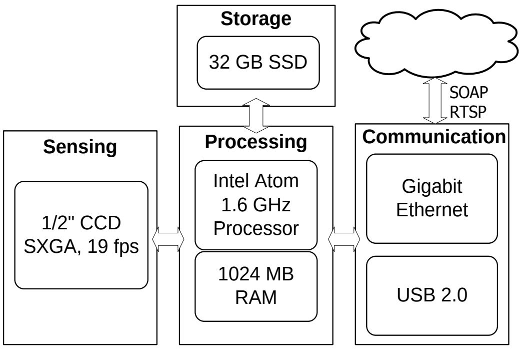

Figure 1: Architecture of the smart camera [6]

Figure 1 shows the architecture of the smart camera that is used as target platform. The smart camera includes a 1280x1024 (SXGA) color CCD sensor that is connected to an embedded processor board. The processor board is equipped with an Intel Atom Z530, 1.6 GHz processor and 1024 MB RAM, connected to a 32 GB solid state disk (SSD) for internal storage. The processor runs a standard Linux distribution that provides flexible integration of additional hardware models and external software libraries. The smart camera is connected to the video network through a Gigabit Ethernet interface. Every time the camera detects an event, it uses a web service interface to send an event description and the associated video sequence to the traffic information system.

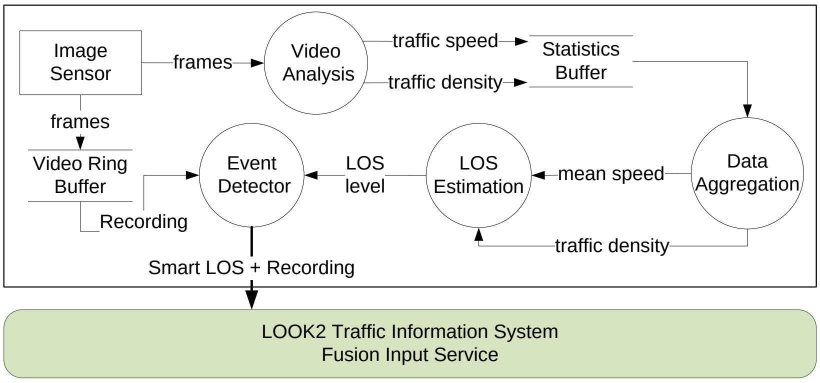

Figure 2: Data flow of the traffic state detection

Figure 2 shows the data flow of the traffic state detection, which is performed on the smart camera. The image sensor acts as data source providing the raw video data with a frame rate of 19 frames per second. The captured frames are written to the video ring buffer and passed to the video analysis module. For each frame, the video analysis module computes the estimated speed and traffic density values and stores them to the statistics buffer. At periodic intervals, e.g. each minute, the data aggregation module uses the data from the statistics buffer and computes the current speed and traffic density estimates. These speed and traffic density estimates are used to calculate the current LOS value as defined in Table 1.

Table 1: Level of service classes used on Austrian motorways [4]

LOS	Description	Speed [km/h]	Density [vehicles/km]
1	Free flow	>80	[0,20]
2	Heavy	>80	(20,50]
3	Queuing	[30,80)	[0,50]
4	Stationary	[0,30)	>50

The event detector compares the current LOS value to the previous LOS value to detect a change in traffic state. If the traffic state has changed, it creates a traffic state description. Furthermore, an encoded video sequence is generated from the content of the video ring buffer. The traffic state description and the video sequence are sent to the LOOK2 traffic information system in real-time for further processing [5].

2.2 Video-based traffic state estimation

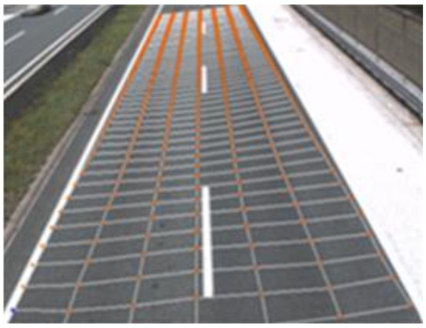

Figure 3: Calibration grid

Figure 4: Analysis area (orange) and motion vectors (blue)

Figure 5: Binary edge image

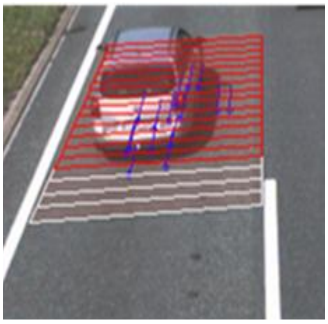

Figure 6: Statistical vehicle counting using occupation state of stripes

The smart camera provides an automatic estimation of the observed traffic state. Offline calibration employs the known lengths of lane markers to calculate the intrinsic and extrinsic camera parameters for a deployed smart camera. Figure 3 shows an example 1m-by-1m calibration grid that was obtained from 10 manually selected calibration points. The calibration parameters are necessary to measure metric distances from the captured image data.

The onboard video analysis uses motion vectors (Figure 4) and edge information (Figure 5) to calculate the mean speed and traffic density values for individual lanes. The video analysis method is only applied in predefined analysis areas as illustrated in Figure 3 (orange rectangle). In contrast to other methods, such as [7], our method does not rely on vehicle tracking or background modeling. Instead, robust cascaded outlier detection is used that facilitates accurate measurements even at difficult weather and illumination conditions. Using the calibration parameters and motion vectors (optical flow), our method periodically calculates the mean speed. Traffic density estimation is based on a robust vehicle counting method that uses binary edge images (illustrated in Figure 5) to obtain the occupancy state for different stripe sections. Figure 6 shows occupied (red) and non-occupied stripe states (white).

3. Evaluation and Results

For testing the video-based traffic state detection, we used 37 hours video data recorded at daylight in July 2011 by a smart camera on the Austrian motorway A12. The smart camera was mounted on a gantry as shown in Figure 7. The video sequences have VGA resolution and a frame rate of 16 frames per second. For estimating the speed from optical flow, we used the frame times that were obtained from the driver of the image sensor. The video sequences include traffic situations with different traffic states and different weather conditions (i.e., sunny, cloudy, light rain, and heavy rain).

Figure 7: Smart camera mounted on a gantry on Austrian motorway A12

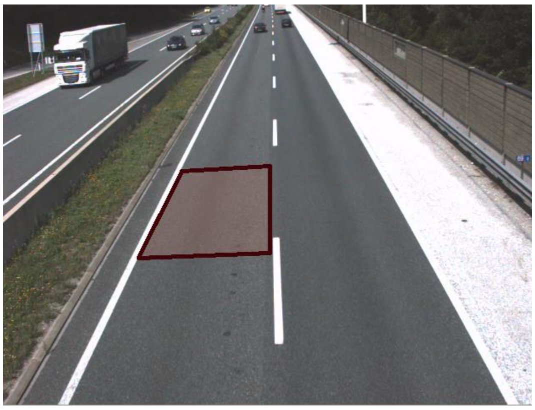

Figure 8: Analysis area (red) used for the evaluation shown in Table 2

Mean speed and traffic density estimates were computed over one-minute intervals. For ground truth we used one-minute aggregated measurements of overhead sensors that utilize triple-technologies (Doppler radar, passive infrared, and ultrasound) for speed measurement and vehicle counting. To evaluate the quality of our traffic state detection method, we calculated the precision, recall, and accuracy of the analysis values for the four levels of service (LOS) defined in Table 1 [4]. Furthermore, we calculated the mean absolute error (MAE) of the speed and traffic density with respect to the LOS categories. The results show a very high accuracy of the video-based traffic state detection method. The evaluation results are summarized in Table 2.

A comparison between the result of the video-based LOS detector (blue line) and the triple-tech sensor (red line) on a two-hour test set, recorded on July 18, 2011 (rainy weather conditions), is shown in Figure 9. The video-based LOS detection method detects congestion and dissipation of congestion in a reliable way.

Table 2: Evaluation results (37 hours test set)

Level of Service	Precision	Recall	Accuracy	MAE Speed [km/h]	MAE Traffic Density [vehicles/km]
Free Flow	0.9942	0.9879	0.9848	2.53	1.11
Heavy	0.6974	0.8281	0.9848	2.55	2.14
Queuing	0.8682	0.9412	0.9893	1.65	4.87
Stationary	0.9583	0.9848	0.9902	2.35	19.10

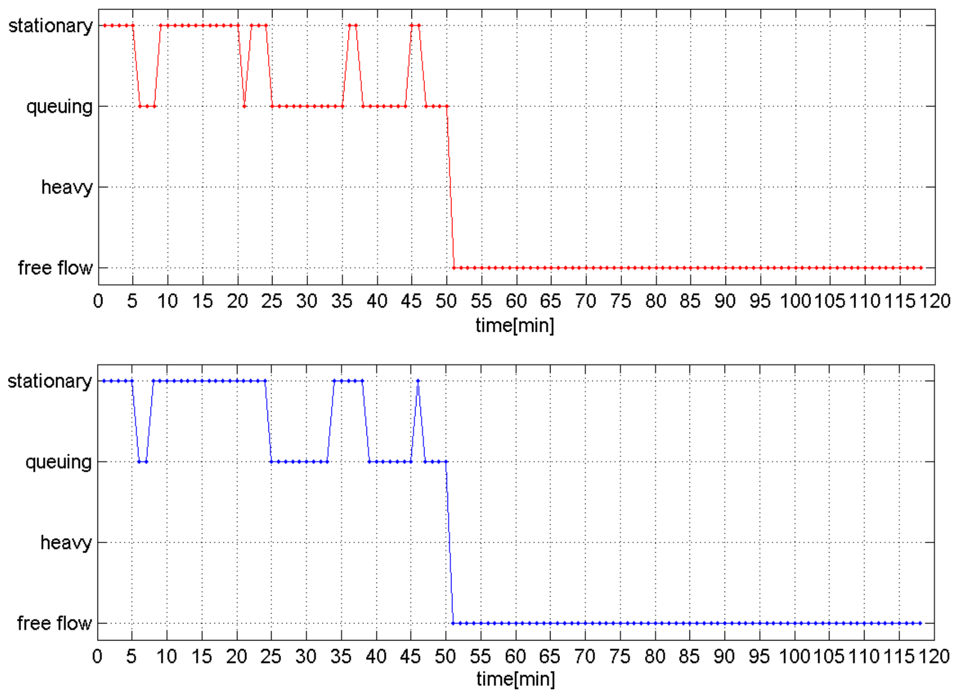

Figure 9: Direct comparison of video-based LOS detection (blue line) to LOS detection of triple-tech detectors (red line) on a 2-hour test set

4. Conclusion and future work

This paper presented an accurate, vision-based traffic state detection system. Live video data is processed on an embedded smart camera in real-time. Any changes in traffic state are automatically reported to the LOOK2 [5] traffic information system. The generated messages contain short video sequences as visual proof that can be used for verification by human operators.

In general, video detection of traffic states provide a number of advantages. First, video-based solutions save costs, especially when existing traffic surveillance infrastructure is used. Second, video detection systems can provide images to human operators for easy verification of traffic messages. Third, in comparison to inductive loops and overhead sensors, cameras can be mounted more flexible and measurements can cover a larger area. Today, most video analysis systems rely on centralized infrastructures, where video data is analyzed on a central server, leading to a potential bottleneck for large-scale video networks. Decentralized systems, as described in this paper, rely on local processing of the obtained image data, which leads to more scalable and more flexible video networks.

Especially for temporary maintenance areas, video-based traffic state detection on smart cameras appears promising. Based on the described results, ASFINAG plans to evaluate the implemented system in 2012 at a maintenance area on the Austrian motorway A2 in the Vienna region. A future vision is a flexible self-sustaining (solar powered) smart camera that employs a wireless network connection to report the observed traffic state and video data to a traffic information system.

5. Acknowledgements

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