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Video based Intelligent Transportation Systems – state of the art and future development

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Abstract

Video based sensor systems can play a key role in delivering data for better road planning and traffic management. Smart road technologies will largely depend on data quality and quantity in the future. Video based detection systems, being an indispensable part of intelligent traffic systems (ITS), show huge potentials as they do not only offer a flexible way of data acquisition but are also being developed at a huge pace due to recent evolutions in hardware and software technology. In order to give a better understanding on the methods and potentials of this technology, a structured review is presented which not only includes current applications but also shows future use cases by analyzing the techniques of image processing and extrapolating their results to the future requirements of traffic engineering.

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Keywords: Video detection; incident detection; traffic measurement; ITS; ANPR; Enforcement; vehicle detection; vehicle tracking

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1. Introduction

Traffic and transportation play an important part in modern national economics. Specifically, smart construction and operation management plays a key-role in the efficient use of transportation infrastructure and thus can lead to huge economic benefits. However, many areas still suffer from unused potentials.

Highway capacity strongly depends on unpredictable incidents and accidents, which can lead to severe traffic congestions and infrastructure damage. Work zones, although being planned, result in high capacity reductions while increasing the risk of accidents. Furthermore, critical spots like tunnels and bridges mean a high risk for individual road users. The main challenge of traffic and transport management in these application fields is the necessity of high quality information, in order to be able to perform efficient management strategies and decisions. In future, additional challenges in traffic and transportation have to be handled, concerning new applications like assisted, autonomous and connected driving.

In order to provide high quality traffic data, video systems are already used at high risk potential spots of the road network today, while being manually observed. Intelligent video detection systems enable automatic observation of traffic flow and safety and generate additional efficiency. This paper analyzes the current and potential use of video based ITS in order to provide reliable data in the above mentioned situations.

2. Current video based systems in Intelligent Transportation Systems

Many of today's ITS systems already make use of the advantages of video based data acquisition. While these solutions only represent a small part of all sensor systems used in ITS, it is important to understand their working principles, main advantages and shortcomings. In the following subchapters more details are presented on the current use-cases of video sensors, by sorting them into different groups of applications and focusing on the common technologies used in these groups.

2.1. Traffic analysis

Current application in traffic engineering is the acquisition and offline analysis of traffic data in order to provide valuable information for planning new roads, to increase the capacity of the already used infrastructure and to increase the safety of road users by fast detection of incidents.

2.1.1. Automatic Incident Detection (AID)

The application of incident detection is of great importance in video sensor technology as it specifically focuses the safety of road users. The goal of this technological solution is the automatic detection of dangerous traffic situations such as the presence of a vehicle driving in opposite direction, slowly moving or stopped vehicles. Additionally, some already implemented solutions also include the detection of dropped cargo. This method has already been used commercially for many years (Versavel, 1999), (Michalopoulos, 1991) and has also been focus of extended academic work (Ikeda, Kaneko, Matsuo, & Tsuji, 1999) (Shehata, Cai, Badawy, Burr, & Pervez, 2008). There are several techniques of achieving the goal of detecting incidents but the methods rely on analysis of the entire scene where traffic flow can be observed rather than on the detailed analysis of individual vehicle characteristics such as number plates. Some of the algorithms used are based on the detection and tracking of individual vehicles and use techniques such as model-, region-, contour- and feature based detection and tracking of the objects analyzed. Others use an observation of motion in the scene to measure mean traffic speed and analyze the change through time to detect anomalies (Fishbain, Ideses, Mahalel, & Yaroslavsky, 2009).

2.1.2. Traffic count

In order to be able to effectively plan and manage road infrastructure, a large quantity of traffic data is required. Currently several different methods exist to gather this data, but in general they all are mobile and flexible solutions due to the fact that the considered locations only need to be analyzed for a short period of time. Thus, the techniques used for data acquisition include mobile radar equipment, floating vehicle data measurement and even manual counting (Minge, Kotzenmacher, & Peterson, 2010). In the last few years video based techniques have been used to either conduct a post-record manual counting or use algorithms to automatically (Beymer, McLauchlan, Coifman, & Malik, 1997) (Dinh, 2011) or semi-automatically analyze recorded data. In Zhang, et al. (2007) an automatic method for real time measurement is presented by using uncalibrated cameras.

Directional re-detection of vehicles by automatic number/license plate recognition (ANPR/ALPR) was used to analyze journey start and destination to classify traffic to local traffic (internal traffic), transit traffic (external-external traffic), as well as entering and exiting traffic in order to achieve a macroscopic intermodal traffic model as basis for planning in Bavaria (Germany) by Dobschütz et al. (2014). A similar approach was already researched by Frith et al. (2002) to show that mean journey times as well as season dependent and daytime dependent journey times, collected from ANPR data, could be provided to drivers to make offline recommendations.

2.1.3. State recognition

Another currently considered application covered by video analysis is the traffic state recognition. This application can actually be covered by traffic counting with an additional step of classifying the parameters into traffic state groups like congestion, slow traffic and dense traffic. As this classification is not generally dependent on exact counting of vehicles and speed measurement, other methods are being developed to use less detailed information about individual vehicles to robustly classify states. One possible approach is described in Li, et al. (2013) where optical flow methods and frame differencing was used in order to choose from one out of three traffic states by using video surveillance cameras which show low video quality and cover a large scene so that high resolution vehicle data is difficult to extract.

Pongpaibool et al. (2007) presents a road-traffic evaluation system using image processing, where vehicle volume and velocity is used to classify a three-level traffic state by fuzzy logic.

2.2. Traffic management

Additionally to collecting traffic data for offline analysis and post-measurement management decisions, many of today’s applications are online systems which are used to make fast decisions. Examples are conferring right to hard shoulder use, or to make hardware in the loop based management systems possible, like adaptive traffic lights, which consider the presence of vehicles in the crossing.

Real-time journey time monitoring systems (JTMS) can be used for traffic optimization. Cooper (2004) shows advantages of ANPR for traffic monitoring tasks in complex situations, compared with different methods like inductive loops. In the *M25 Speed Harmonisation* project, a more complex JTMS was built by combining ANPR with different techniques to a congestion monitoring and control system, to reduce congestion and minimize flow breakdown (Paulo et al., 2010).

2.2.1. Temporary hard shoulder use

In many countries, freeway traffic capacity is limited and dense traffic is already overburdening traffic infrastructure. In order to cope with this issue, the hard shoulder lane is often used in order to increase capacity of the freeway. The main problem with making use of hard shoulder is ensuring that no objects are present on the lane, so that safety of road users can be guaranteed. Video detection systems are currently implemented at some of these locations to provide useful information about the state of the hard shoulder lane (Aron, Cohen, & Seidowsky, 2010). This helps operators in their decision by not only ensuring a better detection of dangerous objects on the freeway but also shortening the decision time.

2.2.2. Closed loop sensor systems

Another efficient way of using video sensor systems is the online use of sensor data to control other actuators of ITS systems. One example of such solutions are adaptive traffic lights, which do not behave periodically just based on the pre-programmed traffic light phases but also react to other parameters like the presence of vehicles, their number and also time period of vehicles being stopped at the intersection. Few information about video based solutions is available in research literature, many solutions are based on thermal imaging or loop-detectors. Basavaraju (2014) mentions image sensors for traffic sensing. In Rachmadi, et al. (2011) the development and use of such systems is also presented, where the main parameter used for signal adaptation is the number of vehicles present at the traffic light. In order to count vehicles, a vehicle detector based on Principle-Component-Analysis has been implemented in this work, although other methods can be used depending on the parameter required. In many commercial technical systems, the only parameter used is the presence of at least one vehicle at the traffic light, in which case a more straight-forward method like Background-Modeling for a given Region-of-Interest (ROI) can be used.

2.2.3. Access control

Aalsalem et al. (2015) present a parking lot monitoring and management system using ANPR to identify vehicles. This system helps to overcome manual work like controlling the authorization for reserved parking, monitoring vehicle damaging and vehicle parking lot retrieval.

2.3. Enforcement

Enforcement applications strongly rely on vehicle identification methods to automatically punish breaking of the law in traffic situations. Since detected violations can and should be verified or rejected to avoid mismeasurement, system sensitivity is typically more important than specificity, but false alarms have to be within a reasonable order. Since vehicle identification is mandatory to target the right person, data security becomes very important, due to potential data abuse.

2.3.1. Speed camera

Current speed limit enforcement is typically implemented by static or mobile radar speed measurement systems or time of flight laser pulse measurement. In Germany, Vidit Systems GmbH has developed a certified system to measure vehicle speed from Closed Circuit Television (CCTV) quality video images in traffic monitoring centers. For current speed limit enforcement, measurement must be robust and accurate so that it can’t be challenged by the violator. For the same reason, measurement must be transparent and image proofs must be usable to reconstruct the measured velocity. Vehicle identification only has to be performed after a speed limit violation could be observed, no personal data has to be saved for inconspicuous road users.

2.3.2. Average speed control

Speed Check Services (in Germany and Austria called “Section Control”) are used to measure the average speed of a vehicle over a fixed route of any distance, disabling the driver to temporarily reduce velocity at local speed enforcement stations. Speed Check Services (SPECS) need re-identification of single vehicles to measure the time needed to pass the second station after it was detected at the first station. Current systems use ANPR for re-identification (Paulo et al. 2010). Compared to current speed measurement, average speed control has additional issues on data security, since identification data has to be saved until the vehicle passes the second station before it can be dropped or a violation can be registered.

2.3.3. Red light enforcement

Red light enforcement at traffic lights solved by vision systems has the advantage to provide additional image proofs where both the traffic light state and the license plate of the vehicle is visible. Research focuses on road user education effects during and after usage of red light enforcement cameras, like Martinez et al. (2006) and Porter et al. (2013).

2.3.4. Toll collection

For automatic toll collection, automatic vehicle identification is mandatory. The solution of Soomro et al. (2012) uses ANPR (although they call it vehicle number recognition – VNR) to identify a vehicle and compare it to a database to add information about vehicle type and charge toll tax.

2.3.5. Mass surveillance

Automatic vehicle identification allows the user to observe the whole camera network, telling police forces whenever a registered vehicle could be identified. False alarms should be reduced to a minimum for both, false suspicion of innocent and manual correction work. Not to mention that those systems have a high risk of abuse if not secure enough.

3. Technology groups and their applications

In this section, a camera detail resolution based categorization of technological methods is introduced, a matrix is provided for assigning applications to technology groups and the assessment is discussed. For algorithmic details of video techniques, Kastrinaki et al. (2003) provide a comprehensive survey.

3.1. Vision detail levels

In order to group different computer vision and image processing techniques and to provide a link between applications to algorithmic solutions, three categories are presented. The main parameter used for categorization is the image detail resolution which can be acquired from the recording camera. Thus, this work separates methods which are based on the analysis of large field of view scenes, like surveillance cameras on highways overlooking many hundred meters from techniques being dependent on high detail information like number plate and as such require a small field of view setting with high sensor resolution. In the following the categories used are presented, while Fig 1. gives a visual impression of them:

1. Traffic webcam resolution: Low framerate, low resolution per vehicle cameras to provide a quick overview of current traffic state for a human spectator. Those cameras might be used in urban areas or highway. Often live stream data is available for anyone, since low resolution doesn’t allow an identification of single vehicles by license plates. Main intention for this choice is the necessity of as few cameras as possible to cover a large traffic network and to limit operating costs. The large space between camera an observation area causes greater dependency from unsuitable environmental conditions.
2. Traffic surveillance camera resolution: Standard framerate, high quality resolution per vehicle, enabling real-time traffic observation with enough detail so an observer gets a fast and reliable scene overview in case of traffic incidents. Those cameras are used densely in critical areas like tunnels or bridges, where a limited area has to be observed.
3. High-detail camera resolution: Very high resolution per vehicle to identify details of a single vehicle, combined with high framerates not to miss a vehicle. These cameras can either be of extremely high resolution to cover some area of the street, but they often reduce the field of view to limit processing complexity and redundant information, so one camera per lane per station is needed. Therefore, no dense road covering of these technologies can be assumed. Limiting the field of view can be a relevant advantage to control environmental effects e.g. by using artificial light sources by night.

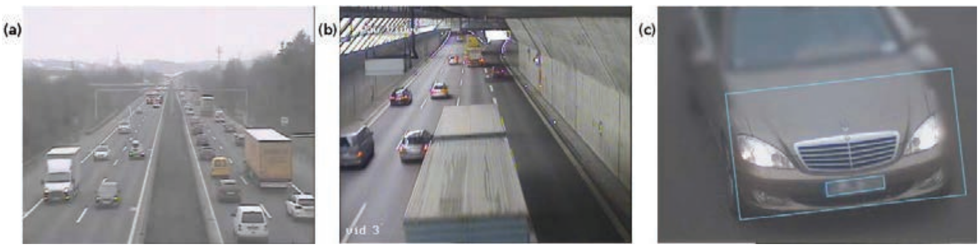

Fig. 1. Camera detail levels: (a) Webcam quality; (b) Surveillance quality; (c) High-Detail quality (Dobschütz et al., 2014).

3.2. Application-Technology-Matrix

In this subchapter a matrix is presented to give on overview at the applicability and efficiency of implementing different applications provided in chapter 1 by using technologies grouped by the present camera information detail.

This matrix can provide valuable information on choosing the optimal technical solution in a given application, while considering alternative make of use of already developed image processing techniques.

Table 1. Application-Technology-Matrix.

Application groups \ Technology groups	Webcam resolution	Surveillance camera resolution	High-Detail camera resolution
Traffic analysis			
Incident detection	-	++	-
Traffic count	--	++	(+)
State recognition	++	+	(+)
Traffic management			
Temporary hard-shoulder use	-	++	--
Closed-loop sensor systems	-	++	(+)
Access control	--	-	++
Enforcement			
Speed camera	--	+	(+)
Average speed control	--	-	++
Red light enforcement	--	(+)	(++)
Toll collection	--	--	++
Mass surveillance	--	-	++

As can be observed from Table 1 different technologies are more or less suited for different tasks in ITS. The matrix includes an assessment of the usability of the already defined technology groups in different application clusters, by using a scale consisting of four rating grades. Thus “- -“ and “-“ mean a total or partial inability to solve a given task with specified techniques included in the technology group. On the other hand entries consisting of “+” and “++” point to a possible and respectively highly efficient solution of the given task. Additionally, entries which are surrounded by brackets imply potential drawbacks due to undesired side effects or limitations of using the specific technology. In the following subsections, more details to the assessed entries are given, by partly describing the used methods and technologies and also discussing advantages and disadvantages for different applications.

3.2.1. Webcam resolution

As already mentioned in subsection 3.2 methods used in the technology group “Webcam resolution” rely on the interpretation of image data gathered from cameras which cover a very wide scene and often deliver video data in a low frame rate. Thus the implemented algorithms and their requirements are well adapted to these circumstances. This group may include a broad range of algorithmic techniques from simple background modeling and segmentation of foreground blobs to detect parts of images not included in the determined background image, movement analysis by means of optical flow to approximate mean traffic speed and frame differencing to detect the presence of movement between consecutive images in the video sequence. Additionally, machine learning techniques, like neural or bayesian networks can also be used to interpret image content and thus classify traffic parameters into different traffic states.

Thus, this technology group is well suited to applications which aim to coarsely characterize the traffic like identifying slow moving or free flowing traffic and to automatically detect traffic congestion. From these considerations, the most suited application is the automatic state recognition for the purpose of informing road users about the traffic conditions on certain highway sections. It is to be mentioned that for this specific task, techniques based on coarse resolution cameras also have the advantage of being low priced, as the low requirements can already be met by lower quality cameras and the wide scene coverage also leads to a lower number of required cameras to cover large sections of road infrastructure.

On the other hand, all other applications are quite difficult to achieve with this technology group. This is due to the fact the low resolution image data does not deliver the detail required by other surveillance task. As an example, applications included area of enforcement all require high resolution images in order to be used in court. They are also often relying on identification of specific vehicles based on their number plates or at least their make and model, which are all parameters that cannot be identified in a wide perspective camera. Although traffic management applications could be theoretically doable based on congestion detection, the low resolution cameras are often affected by environmental side effects, so a large false detection rate can be expected. Implementing a hardware-in-the-loop system based on a sensor which cannot deliver steady data in high quality could lead in inefficient management of road infrastructure. Especially systems which could have an impact on the safety of road users, like incident detection and temporary hard-shoulder use, will tend to be inefficient when low accuracy sensor data is used.

3.2.2. Surveillance camera resolution

The technology group of surveillance camera resolution is defined as using mid-detail cameras which can overlook a portion of several tens of meters and at least two lanes, but are not able to record exact features of vehicles like number plates or identify drivers sitting in vehicles. Techniques implemented in this group are aimed to analyze the composition of the traffic and movement of individual vehicles. They are often based on the detection and tracking of individual vehicles with a precise camera calibration in order to measure the mean velocity of vehicles through several frames. Algorithms implemented for detection and tracking consist of region-, model-, feature or edge-based techniques and some machine learning methods could be used for post-processing steps like the detection of anomalies on highway or measuring the number of vehicles on a lane. This leads to a good applicability of the technology in many tasks which do not require exact identification of the vehicles but do rely on trajectory approximation or good accuracy in vehicle counting. Examples for such applications are found in traffic analysis for high quality offline data acquisition or in reliable detection of hazardous situations in critical sections like tunnels or on bridges.

Additionally to plain traffic analysis, automated traffic management systems can also be efficiently implemented with mid-resolution camera technology as they reliably can determine traffic parameters. Some of current hard-shoulder use systems automatically detect the presence of objects on the considered section and generate an alarm in a hazardous situation. There are several high resolution cameras, which were specifically developed for this task. Additionally, as presented in section 2, adaptive traffic light systems can also be efficiently deployed with video based sensors found in this technology group as the required parameters could include the presence, number or stop period of vehicles.

On the other hand, access control systems often depend on the exact identification of vehicles. Although some features, like vehicle class, color, rough size could be determined in surveillance cameras, the settings of these cameras often make it difficult to reliably read to number plate or the model of a vehicle. High resolution cameras pointed at the feature used for identification are more suited for this purpose. This reasoning also leads to difficulties in applying mid-resolution technologies in most enforcement tasks. As the detailed information without exact focus on an image region can only hardly be detected, the recorded data is not suited in court. Through the possibility of accurately measuring vehicle speed, mid-resolution techniques could be used to automatically detect speed limit violation but complementary systems are necessary to exactly identify road users. This shortcoming is represented through brackets in the Application-Technology-Matrix.

3.2.3. High Detail Camera Resolution

Today's most often used high detail camera resolution technique in traffic applications is the ANPR method, which visually detects and reads license plates from vehicles to provide some information. ANPR is claimed to be topic of research since the 1970s (e.g. Gurney et al. 2012) and it is still of high interest. Lately, a state-of-the-art ANPR review was published by Du et al. (2013), accuracy was measured and interpreted by Rhread et al. (2012) and thoughts about defining an international standard were gathered by Gurney et al. (2012). Different works focused on further general improvements of ANPR methods, like Gorovyi et al. (2015), Bhardwaj et al. (2014) and Ajanthan et al. (2013). High detail camera resolution techniques are applied locally, gathering as much of information at a single location as possible, targeting only a few meters on the road. ANPR can be used for various tasks more or less efficiently discussed later. Common methods of ANPR are identification of vehicles and their owners and re-identification of vehicles to derive information of travel time between two ANPR stations. In theory, vehicles transporting dangerous goods could be detected by sign detection, but no current implementation is known to the authors. In general, high detail camera resolutions increase the risk of unintended capturing of road user's private information or even have the aim to capture those (e.g. license plates).In traffic management applications, high detail resolution is mandatory for access control, where road users can be identified with ANPR and access can be granted or denied. Closed-loop sensor systems rely on vehicle presence information on one hand and knowledge or assumptions about vehicle routes on the other hand, which can be solved by ANPR due to (re-) identification, but many stations have to be implemented, for example one ANPR station for each way in a junction. For temporary hard-shoulder use, high detail cameras aren't applicable because of their sparse implementation and limited field of view.

High detail cameras are best suited for enforcement applications, where privacy issues are disabled or handled anyways. Average speed control is typically realized by two or more ANPR stations of any distance. The same method can be used as a speed camera for measuring local speed between two close stations, but with and overhead in hardware installation needs.

For red light enforcement, ANPR is desired to reduce manual effort, and ANPR can detect vehicle presence in a specific forbidden area. But high resolution for ANPR in combination to large field of view for capturing the red traffic light in the same image leads to some hardware overhead. The alternative is to provide the red light interval information directly to the ANPR system which introduces some overhead in system calibration and the need to trigger another camera for proof photo. For Mass surveillance and toll collection, vehicle presence and identification, compared to some kind of data base is necessary which is exclusively and efficiently solved by ANPR in video based area.

4. Future applications

In the sections above, the current state-of the art in video based ITS was presented mainly focusing on present commercially available solutions. Throughout the analysis, some methods proved to be well suited for new applications, which are not common in todays ITS. Some of these possibilities will be discussed in this section by grouping potential applications in short-term, mid-term and long-term implementations based on the predicted time for development and market acceptance.

4.1. Short-term

Although in individual projects and academic works the task of automatic recognition of traffic states on highways have been tested, there still is much potential in spreading this technology to a large number of web-cameras already being used for video broadcast. In many countries, developing software solutions which use already available traffic cameras could deliver a huge amount of traffic data not reached at the moment.

Additionally, many critical sections of road infrastructure are still not covered by automatic incident detection systems although being surveilled manually through cameras. In a short term, other areas could also be covered by automatic video surveillance like bridges, urban areas and sections which could pose a potential threat trough terrorism and other forms of life threatening situations.

4.2. Mid-term

As a mid-term potential, video based technologies should be implemented in changing environments like road construction sites and work zones. While being continuously varying, these sections show a high risk for road users and also require new algorithms which are not only adaptive but also are highly robust in delivering reliably data. If these methods are available in the future, smart work zone and road construction management could be carried out in a more time efficient way and would also be safer to both road users and work teams.

Another yet to develop technology is the area of high-detail traffic visualization. Through the means of automatic vehicle detection and tracking, microscopic traffic data can be made available to a real-time visualization which makes the work of operators more efficient and less exhausting.

4.3. Long-term

In order to keep track with technological advances in the area of high-automated mobility, the developers of sensor systems built into the infrastructure need to consider the possibility of delivering data to many more users besides vehicle drivers. Especially the communication with highly automated vehicles will play a key role in supporting safe driving in the future, as sensors built into vehicles could suffer limitations due to geometric constraints or software manipulations. Camera based sensor technology needs to complement the measured data in vehicles and Car-2-X communication needs to secure a real-time transfer of useful data to all affected devices.

5. Conclusions

In this work, different traffic applications solvable by video based systems were described and ordered to competing groups of stationary traffic cameras with their advantages and disadvantages. Three different camera groups were identified: webcam quality cameras, surveillance cameras and high detail cameras. Webcam quality cameras with low resolution and framerate are only able to provide coarse information but allow a dense implementation because of their low cost and large field of view. Surveillance cameras provide high quality information due to a better resolution and a moderate field of view, enabling high quality information extraction in the covered field of view. High detail cameras provide additional information with a narrowed field of view and are able to compute or deduce lots of information, but not all applicable tasks are solved optimally by them. An Application-Technology-Matrix was provided to give a smart overview of applicability and reasonability of solving a specific task with some technology group.

A short prediction of future applications was given to show opportunities and diversity of research topics in video based intelligent transportation systems.

Based on the research work conducted for this paper, it can be concluded that video based technology provides an optimal solution for a wide field of traffic applications in ITS. However, target-oriented deployment and development is preferable to achieve a high user acceptance of the technology. Additionally, new areas need to be considered in order to keep track with overall technological advances.

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