Applications of Video Surveillance Systems for Traffic Data Acquisition

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Abstract. The process of urbanization raises city population and extends city boundaries, which leads to heavier road traffic, environmental pollution and bigger financial losses. Due to spatial structure and influence of many factors on transport conditions, the transport system requires complex management methods. To be widely adopted, traffic management projects have to have the lowest possible price and highest effect on transportation. To accomplish these requirements, city authorities have to know what and where the halting points are. Using existing CCTV cameras for traffic purposes can empower authorities to easily obtain city-wide traffic data. This paper analyzes the benefits and problem areas of CCTV systems when used for traffic surveillance and present different ways for improving reliability and accuracy of these systems. Examined areas are camera settings, optical filters, mounting place, digital image processing techniques for image enhancing and object extraction and objects filtering based on their properties.

1 Introduction

The rising of the world population and the process of urbanization are some of the reasons for differentiation of densely populated city areas. The growth of cities in both horizontal and vertical direction, strengthening of economic links among them and constant searching for profit require more effective ways for people and goods transportation. Road transport arteries connecting residential with industrial and commercial city areas, and highways between cities, gather extremely important role in functioning and growth of every modern country.

Mass usage of automobile transport is constantly increasing since its biggest advantage is door-to-door service. To be able to guarantee normal functioning of the global economical system, road transport systems must be:

- efficient (providing alternative routes, enough capacity, suitable for all vehicles),
- effective (with minimal expense of time and fuel),
- reliable (with minimal disturbance from planned and random events),
- ecological (with minimal environmental pollution),
- safe (with minimal risk for traffic participants).

As reasons for traffic jams, and the ways of reducing them are complex. The ways for improving transport quality may be grouped in the following categories:

- restricting or stimulation of using one or another type of vehicles and traffic reorganization,
- city areas and roads planning consistent with current and future transport needs,
- renewal of old one and constructing of new road infrastructure,
- enhancing of traffic flows surveillance and control.

2 The role of traffic sensors

Intelligent Transportation Systems (ITS) are in use worldwide nowadays and their aim is to improve safety, performance, environmental impact and to provide sustainable development of road transport systems by modern transport technologies.

For identifying the bottlenecks and their locations, as also for revealing and evaluating the possible corrective actions, it is mandatory to have information about the road infrastructure and the traffic flows. The realization of a specific traffic project can influence different aspects of transport conditions and evaluating the project consequences in advance is an important step in its planning. By creating computer models of city or national road networks and by using real stress data acquired by traffic sensors optimal decisions are more easily taken in various situations during traffic management and planning in response to current demand and conditions [1,2].

Traffic flow management relies on up-to-date data for different traffic parameters. In addition to individual vehicle parameters sensors compute generalized indicators describing automobile flow as a whole. This data is used for a wide range of tasks such as:

- evaluation of road load,
- simulation of computer transport models,
- adaptive control of traffic lights,
- identifying of peek hours,
- identifying locations with frequent traffic congestions,
- evaluation of sound and atmospheric pollution,
- determination of the predominant types of vehicles,
- route determination of major traffic flows.

Examples of measured vehicle parameters are:

- used lane,
- direction,
- speed,
- type of vehicle,
- weight of the vehicle,
- length of the vehicle,
- time of passage,
- registration number,

On the basis of these parameters following indicators can be computed:
– average flow speed,
– distance between consecutive vehicles,
– loading degree of the road section,
– air and noise pollution,
– existing or impending congestion,
– traffic violations.

For the realization of the most suitable project meeting expected improvement of transportation conditions it is necessary to clarify beforehand the following questions:
– what is the transport problem,
– what information is needed for solving the problem,
– what are the specifics of the road section and the traffic.

Having defined the above points a project may proceed with the choice of technology and specific road sensors meeting the requirements.

3 Traffic sensors

The two main groups of traffic sensors are:
– in-vehicle sensors,
– road sensors.

The first group of sensors represents devices such as mobile phones, GPS receivers and RFID transponders, mounted in each vehicle and monitoring only this vehicle. In this case, many devices are used for ensuring proper data and covering larger area of the road network.

The second group of sensors is installed at a specific point of the network for measuring local traffic parameters only. One road sensor can monitor multiple lanes with the same or different directions. This group includes video surveillance systems for acquiring and analyzing traffic data. These are passive sensors covering long road section, providing simultaneously video signal from the place, which is the major difference compared to other types of road sensors. For extracting useful traffic data from the video signal different algorithms for video image processing are being applied [2].

4 Video road sensors

Video road sensors are based on video surveillance systems and techniques from machine (computer) vision for analyzing of video frames in the process of acquiring data for the vehicles visible in the frames. The video camera frames can be processed either centralized in the control centre or locally by each video camera.

In the first case, computers are located in the data centre and are processing video streams from remote cameras, as one computer or controller can handle multiple video streams. In the second case, video cameras are equipped with integrated computer modules for digital image processing. These video cameras transmit only traffic data to the control centre, but it is also possible to stream live video. The choice of the video system type depends on various factors, whereas it is possible to establish a hybrid system including already installed analogue cameras as well as new smart digital cameras. Streaming of the video signal from the cameras can be permanently or when certain conditions are being registered such as abnormal parameter values, a traffic incident or a violation [3].

Video road sensors implement two types of algorithms for measuring vehicle parameters. The first one measures parameters only once in a set point of the video frame, normally when vehicle crosses a virtual line, thus simulating physical road sensors. The other type measure constantly vehicle parameters, as long as vehicles are visible. This process includes tracking each vehicle on each consecutive video frame.

In order to be appropriate for road traffic monitoring, video road sensors must fulfil following requirements:

– automatic detection of all vehicles,
– detection of both moving and stopped vehicles,
– operability under various weather conditions,
– operability in real time.

To be considered a universal tool in transportation projects video road sensors must also provide:

– high accuracy of the measured parameters,
– simplicity of installation and maintenance,
– high fault tolerance,
– ability to exchange information with other systems,
– ability to visualize and analyze collected data.

5 Advantages of video sensors

In the big cities, there are already established systems for video surveillance of various public places, including important road arteries for the purpose of security. The signal from these video cameras can be used simultaneously for the purpose of traffic monitoring and safety. In this case the whole infrastructure is ready and necessary investments are substantially lower. What remains to be done is the installation of computer equipment in data centres for processing video signals from cameras. This significantly reduces the time for building the system.

With the ability to cover a large number of lanes and a long road section by one video sensor different road situations can be detected e.g.:

– speeding,
– stopped or parked vehicles,

– driving in forbidden lane,
– driving in wrong direction,
– crossing a continuous line,
– red light crossing,
– smoke in tunnels,
– debris on the road.

This allows obtaining extensive information about the traffic by installing a small number of devices. Installation of new cameras can be done on the side of the road, as not to hinder normal traffic.

Adding new features to the processing of the video signal can be done in stages, starting with vehicle counting and completing the system with their classification and violations and congestion monitoring. The modular structure of the software system will further accelerate the introduction of the system in operation and will allow the creation of optimized solutions for every specific project. The general use of video cameras eliminates the need to install other cameras for obtaining video images used by supervisory authorities to assess the traffic situation.

Thanks to the digital nature of the video sensor functioning and modern communications, it is possible to analyze video signals from anywhere in the world. To reduce needed bandwidth of the communication system, it is advisable to send first only a picture and after the situation has been assessed by operator to begin video broadcast in real time.

6 Disadvantages of video sensors

Difficulties in the operation of video sensors are a consequence of the difficulty in extracting the necessary data from the video footage in degraded frame quality, caused by the following factors:
– low light and bad weather conditions,
– low quality of video frames,
– scene complexity.

6.1 Low light and bad weather conditions

Insufficient light on the road is a major problem for video sensors. Separating cars from the background becomes unreliable, which leads to missed cars. Many algorithms for detecting cars do not work as well at night.

Bad weather such as heavy rain, snow and fog reduces the road lighting and image contrast and may introduce noise in the frame. Visibility is also reduced and the recognition of distant vehicles becomes difficult. The algorithms which use specific points or object edges for identifying and tracking of vehicles will not be able to reliably detect vehicles due to reduced contrast. Reduced number of the contours in the image as a result of decreased contrast is used by some systems for smoke detection in tunnels.

6.2 Low quality of video frames

The quality of video frames is influenced by the following video camera elements:
– camera lens,
– image sensor type,
– automatic video functions.

Optical distortions are defects caused by a simple single lens or other imperfect optical system due to some phenomena and geometrical characteristics of light passing through each lens. Each lens suffers, to some extend, from various optical defects. As a result of these effects, the image created by the optical system is poorly focused, distorted or with changed colours. Distortions are of several types and are removed by a combination of different lenses. Completely removal of all distortions is impossible, and only these distortions that hinder the specific task are removed. This is done through complex combinations of lenses of different shapes, made of glass with different refraction ratios and combined in a way so that to remove all undesired image faults. Compensating the various distortions is necessary for the proper measurement of vehicle speed, trajectory determination and classification [4].

A smaller photosensitive element creates a stronger noise in the image and if the frame resolution is also low, the details in the image become indistinguishable, which worsens the overall accuracy of the extracted data.

CCD and CMOS sensors represent two different technologies for capturing digital images. Each has its strengths and weaknesses depending on the application and neither of the two is clearly superior to the other. For the purpose of traffic monitoring the frame speed is the one of the standard TV and the time for digitalization of the frame is not so important. But it is important to minimize the noise, keep the colour uniformity and light sensitivity at high levels because traffic cameras work 24/7. Characteristics of both technologies are shown in table 1.

Table 1. Characteristics of image sensors.

Indicator	CCD	CMOS
Chip output	Voltage (analogue)	Bits (digital)
Number of amplifiers	One	For each pixel
Noise level	Low	Medium
Complexity	Low	High
Dynamic range	High	Medium
Colour uniformity	High	Low to medium
Conversion speed	Medium to high	Higher
Power consumption	High	Low
Heating	High	Low
Pixels density	High	Medium

CCTV cameras have a set of functions for automatic determination of parameters for frame capturing depending on ambient conditions. For road sections monitoring, changes in the scene are small and slow, and the most important factor is the total light during the day. Some functions are not needed and removing or disabling them facilitates the processing and reduces the cost of the camera. These unwanted functions are BLC (Back-Light Compensation), AWB (Automatic White Balance), AF (Automatic Focus) and AI (Automatic Iris). In the absence of light sources behind the road BLC should be blocked. The colour change with AWB can reduce the reliability of the algorithms using colour information for detecting vehicles. AF and AI functions apply mechanical techniques which reduce the reliability of the camera and increase the complexity and cost. After mounting the camera the focus remains unchanged and the AI function is replaced by optical filters, AGC and AES.

6.3 Scene complexity

When the video camera is mounted close to the ground or directed almost perpendicular to the road, it is possible for nearby vehicles to get overlapped and even hidden one by another. This leads to wrong counts or incorrect parameter values of these cars. Merging of close cars is possible also during periods when the sun is close to the horizon. Then cast shadows are longer and may fall on adjacent cars [5].

The presence of moving objects near the roadway or of ones often passing through it can also lead to the adoption of these objects by the processing algorithms as real cars. In this case, false alarms of traffic violations or other dangerous situations are more likely to be generated by the system. Such unwanted objects can be:
- wild animals,
- pedestrians,
- moving trees,
- buildings.

Trees located adjacent to the road may hide part of it or be source of movement in the frame (moving cars) in the presence of wind. Light sources at night can blind the camera, illuminate excessively part of the road or be recognized as car headlights. Glare from road surface (especially when wet) or vehicles surfaces in some cases can be the cause for the impossibility to determine the vehicle type, the fusion of cars and road and the loss of colour information. Even if these unwanted objects are out of the analyzed area of the frame, they can change various parameters used in frame processing, such as image thresholding and objects filtering values.

During observation of roundabouts and squares with divers streams of cars and pedestrians, where bus stops are present together with traffic lights, recognition and filtering of the various objects and determination of their behaviour is very difficult. If the road is curved and the system checks for violations as prohibited overtaking or driving in prohibited lane, the vehicle trajectory will be an arc and not straight line, which complicates its analysis.

7 Hardware methods for improvements

In creating a universal tool for traffic monitoring for all tasks and conditions, with regard to the accuracy and reliability of the final results, it is appropriate to overcome the problems at each stage. The optimization process has to start with choosing the camera and its location, to continue with setting camera parameters and to close with video footage processing and filtrating algorithms and parameters.

7.1 Mounting place and video camera parameters

The cameras are mounted on a certain height above or on the side off the road. They have to be pointed down towards the road, and all observed lanes have to leave the frame at the top and bottom, not sideways. The sky must not enter the frame in order to reduce ultraviolet light, brightness changes, camera dazzle by headlights, etc. Surrounding objects and light sources, which may hinder processing algorithms, must also be minimized.

Stationary cameras without zoom capability and progressive frame scanning are used. Interlaced scan cameras require further signal processing before information from the signal can be extracted.

To avoid having to adjust the iris, lenses with shorter focal length have to be used to keep the depth of field long enough during the night, when the iris opens to allow more light. A wide-angle lens provides a larger viewing area, but it introduces also heavier geometric distortions.

When expected that the substructure will experience vibrations, it is necessary to use a camera with image stabilization. It is sufficient to compensate the linear displacements of the image sensor, because there is usually no rotation. Stabilization can be achieved in two ways – mechanical, by movable lens and digital, by image processing.

Useful video functions are AGC (Automatic Gain Control) and AES (Automatic Electronic Shutter). AGC function adjusts the gain of analogue signal from image sensor at different levels of illumination. This function is useful during the evenings and night. AES function is responsible for the shutter speed, which affects the brightness of the frame. For many algorithms is important that the difference between consecutive frames is minimal. To achieve this, the two functions should work, so that the parameters of the frame remain constant, even when the amount of sunlight changes. Rapid change in brightness of the image is observed when a large vehicle passes near the camera. Such a vehicle occupies big part of the frame and the large surface reflects more light toward the camera.

7.2 Additional optical filters

The overall quality of the video frames can be improved by adding optical filters in front of the camera lens. Filters for contrast enhancement are suitable for places with frequent fog or haze. Polarizing filters reduce the glare from water, wet and metal surfaces such as the coverage of most vehicles. Ultraviolet and infrared light filters improve colour reproduction and durability of the image sensor in the video camera.

7.3 Processing units

The performance of microprocessors is growing steadily and today it is sufficient for the purpose of digital image processing in real time and in particular for video traffic monitoring. There are different technologies for the construction of computer modules for general and specialized applications, such as:

- digital signal processors (DSP),
- system on a chip (SoC),
- field-programmable gate arrays (FPGA),
- application-specific integrated circuit (ASIC).

Some of the solutions use hard-coded algorithms that can not be changed once the chips are manufactured or once software is written to the chip. Since all functions of video traffic sensors are realized by a software program it is desirable to be able to change and enhance them after initial system deployment. In this sense it is better to use standard solutions such as DSP processors, enabling easy software update.

When using a dual-core DSP processor, each core can process an individual frame, so the cores will have twice the time to finish the processing. Another option for optimization is to separate the series of processing operations between the two cores. So the volume of tasks for each core will be smaller and will require less time.

8 Software methods for improvements

Having selected the optimal location and camera, here comes the optimization of the filtering and processing algorithms for video signal analysis. Filtering is a basic method for removing erroneous values in the data, which increases the accuracy of the final result.

8.1 Camera and traffic parameters

In visual identification of vehicles, the ability to set different system parameters is an advisable step. The configuration of the observed road section is static so it is possible to preset parameters describing the road, camera characteristics and normal ranges of traffic parameters. Some systems rely on the relationship between the size of the frame in pixels and the actual size of the observed road. It is even possible by setting the actual coordinates of several points of the frame to determine three-dimensional location and type of vehicles, without using stereoscopic camera [6]. Such configuration parameters can be:

- road length,
- number and lane boundaries,

– driving direction for each lane,
– real distance between virtual sensors,
– mounting height of the video camera,
– viewing angle or focal length of the lens,
– central point of the intersection,
– zones not subject to analysis.

8.2 Processing and filtering parameters

Noise filtering should be done in two stages. The first stage covers video frame processing before measuring vehicle parameters and the second involves the evaluation of the estimated parameters.

The first stage could include reducing colour noise, contrast adjusting, colour normalization, application of smoothing filters, frame thresholding or difference between two consecutive frames and more. Reducing noise in the image is useful in cases where optical flow is calculated. Normalization of frames is aimed at eliminating unevenness in brightness. The application of morphological operation "erosion" on the binary image removes small objects occurring due to noise, rain, movement of trees, birds, animals, etc. In order to eliminate false objects or those which are not important, an area of interest must be set and only in this area objects are analyzed. This is useful when is not possible to avoid areas close to the road with common movements like sidewalks and parking spaces.

It is possible that even after frame filtering and separation of potential vehicles, the extracted data contains objects that are not cars or with incorrect parameters due to some reason. Such objects are moving with unreal speed, suddenly changing direction, got too large or too small. Characteristics of the vehicles slightly change between successive frames and the big difference have to be considered as not normal and corresponding object filtered out. Example of a jump-like change of the parameters of a vehicle is where two or more vehicles overlap visually or by their shadows. Additional filtering parameters can be the valid ranges for vehicle size. For example, motorcyclists and cyclists occupy significantly less space than cars, and trucks and buses more space. This space can be measured during on-site trial tests and later setup in the software. Only after this stage the system can proceed by reporting the real count of vehicles, calculation of additional traffic indicators and checking for violations.

8.3 Vehicle detecting algorithms

In the theory of digital image processing, there are numerous operations. Different analyzing algorithms apply different sets of operations for a given task and therefore their efficiency and accuracy is varying and depends on many factors. The main task of these algorithms is the detection of moving and stopped vehicles on the road. Other task may include speed and vehicle type recognition. Development of fast and reliable algorithm is a process requiring time and deep knowledge. Different weather and road conditions may require the use of several methods to achieve accurate data in a wide range of situations.

At present there are numerous methods for detecting objects in video footage. They can be classified into 3 groups:

- methods using prior information about objects,
- methods based on movement or change in video footage,
- methods based on wave analysis.

Preliminary information used to identify an object as a vehicle can be symmetry, colour, contours of the vehicle, the presence of round objects (wheels), 3D models and headlights. Symmetry in the horizontal and vertical directions can be used to distinguish vehicles from other objects. Due to the typical colour of asphalt and its uniformity, opening the car can be based on colour differences. The presence of a dark shadow is a sure sign of the presence of a car. This method is limited to places with no side objects near the road.

On the basis of uniform colour and the lack of contours in the image and during vehicle passage contours appear, which can be used to classify vehicle by type by creating its wire 3D model. Change in a certain way of intensity of the image, also could be signal for the presence of a vehicle.

Classification of vehicles according to the distance between the front and rear axle (wheels) requires the camera to be positioned laterally and preferably perpendicular to the road. Another method used during the night time is the detection of a pair of punctuated bright objects representing vehicle's headlights.

All methods discussed so far use spatial features to separate vehicles from the background. Another used method is the calculation of optical flow. The vector field of the moving object is called optical flow. Here several frames are used, i.e. the temporal characteristics of the objects. The calculation of optical flow is a heavy computational task that is only applicable to moving objects. This prevents the method from applying on congested roads and intersections, because stopped vehicles can't be detected.

Wave transformation is a new method for image processing. Movement of vehicles is described in full 3D spatial-temporal model covering several video frames.

8.4 Computation difficulty and CPU power

Another area influencing the final results and functionality of the system is the computational difficulty of the algorithms. Since it is important to obtain data in real time, it is necessary to pay attention to the following factors:

- volume of the video signal,
- the efficiency of the processing algorithms,
- the performance of microprocessors.

Volume of the input signal W is defined as a product of width and height of the frame in pixels multiplied by the number of frames per second and is measured in pixels/s:

$$W = F_W F_H F_S . \quad (1)$$

Where W - volume, F_W - width of frames, F_H - height of frames, F_S - frames per second. The bigger is the frame and higher the frame rate is, the larger the volume of the input signal per second is, which requires a faster processor.

The implementation of additional filtration of the frames or more precise algorithms requires the calculations to be optimized. Common approach for speeding up calculations is to use integer arithmetic, since this type of operations are faster compared to floating point operations. Another optimization can be reducing the volume of the input signal via a pre-resizing of the frames by a given ratio smaller than 1. Frame rate of 10 fps is sufficient to obtain accurate data, but typically the standard TV speed of 25 or 30 fps is used to obtain smooth video.

9 Conclusion

The video sensors for traffic monitoring are well-suited for a wide range of transport tasks because in addition to measuring individual vehicle parameters, they can also detect traffic violations, queues of cars and unwanted situations such as traffic jams. They provide coverage of a large number of lanes on a long road section, which makes them attractive. The lack of necessity for stopping the traffic during installation and maintenance activities, as well as the possibility for using already installed video cameras, makes this solution even more valuable for transport authorities. The opportunity to expand their software functions remotely from the control centre, without changing the cameras, makes from video traffic sensors a promising technology with long life.

The guidelines for future development in the sphere of video traffic monitoring can be in the direction of improving the techniques and algorithms for vehicle detection in the cases of merging several nearby vehicles and working during night time. There are video sensors using stereoscopic cameras addressing the problem with merging of adjacent vehicles. These video sensors determine exact spatial location of vehicles on the road and their type.

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