# MONITORING TRAFFIC BY OPTICAL SENSORS

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## ABSTRACT

*Optical systems are well suited for traffic observation and management. The real-time requirements can be met by implementation of appropriate image processing algorithms in hardware. The use of programmable logic structures offers advantages of high flexibility and low costs. Instead of transmitting a lot of images only the data of extracted objects has to be transferred from the cameras to local and to regional computer networks. Primary and secondary traffic features can be calculated from the object information and further sources as weather forecast, geographical information or knowledge about automobile characteristics. A variety of problems can be solved in this way, e.g., dynamic local and wide area traffic signal management, or optimisation of traffic flow in busy periods. The design of such a system is very complex; it is still under development. Three examples of image processing procedures are given: sensor fusion, stereo image analysis by epi-polar geometry, and estimation of traffic related air pollution.*

*Keywords: traffic observation, sensor network, cameras, image processing*

## INTRODUCTION

Sustainable urban development requires a modern transportation management. Especially such mega-cities as Rio de Janeiro or Cairo have distinct transportation problems. Like many cities in the world they suffer from severe traffic congestion, air pollution, high accident rates, slow traffic and long overall travel times. An efficient transportation management system has to be developed to overcome these world wide problems. This includes reliable traffic observation, traffic control, and dynamic road traffic management in real time [2].

Research and development in computer science contribute to the management of the transportation problems. Monitoring traffic by optical sensors requires the design of new software and hardware for signal processing. The Institute of Computer Science at the Humboldt-Universität zu Berlin is engaged in a project „An integrated optical system for image analysis“ for application in monitoring traffic. Partner in this project is the German Aerospace Centre DLR. The project benefits from the experiences and first results within the DLR-project “Optical Information System for Road Traffic Measurement and Management - OIS” [1]. The basic concept of this system is the use of optical and microelectronic technologies for automated traffic data generation with signal processing based on spatial data. The project objective is the design of a complete system architecture ranging from sensors for automatic traffic detection up to traffic light management for a wide area meeting the requirements of an intelligent transportation system. For such a system a detailed global and local extraction and characterising of the traffic flow has to be realised.

Traffic data measurement systems already exist. Induction loops which are embedded in the pavement are used most. An alternative approach is the use of so called floating car data (FCD). In the FCD technique moving vehicles transmit information about their position and velocity via mobile communication to traffic management centre. This way FCD provides spatial and temporal traffic information. This information is suitable especially for evaluation infrastructure quality or for comparing the road network quality of different cities or districts [3]. But the area based approach of floating car data does not fit the requirements of e.g. a traffic signal control.

Induction loops can measure the presence of a vehicle and its actual speed. A rough classification can be done, but the number of directly determinable traffic parameters is very limited and non-motorized road-users can not be detected. The loops provide reliable data, but the derived information is local and not suitable for a wide area traffic management. The use of induction loops is restricted to observation and analysis of local traffic, mainly traffic nodes and application in traffic light control.

The use of optical systems can overcome these limitations. This way it is possible to get not only cross section related but also road related information and to identify infrastructure deficiencies. The application of optical systems has the potential for an automatic traffic data generation and effective traffic management, for a dynamic wide area traffic control, for traffic simulation, traffic planning and travel guidance. There is a chance of optimising traffic flow on intersections during busy periods, to identify stalled vehicles or accidents, or to give a forecast of information obtained from intersection to intersection. The characterising of traffic flow in different spatial categories allows such a large diversity of applications.

## OPTICAL SYSTEMS IN TRAFFIC CONTROL

Optical systems have a multitude of advantages in traffic monitoring. First of all there is a variety of usable sensors which can be combined in different ways. Limitations from measurement principles in the spectral or resolution range can be compensated, if the combination is complementary. For example, the CCD-camera has a limited spectral range, but day and night vision is possible by combination of sensors for visible and infrared radiation. Several cameras with different views can also help to manage occlusions in the camera field of view caused by traffic signs, trees, or cars.

From image sequences acquired by optical systems the automatic object extraction and tracking can be carried out by using corresponding object recognition and tracking algorithms. The traffic flow can be characterised by traffic object parameters and road or lane related amounts if each traffic object is identified and specified. Typical object parameters are location, speed, size, shape, colour of moving and non-moving traffic, distances to the traffic behind and ahead, as well as vehicle acceleration or location in object space. Typical lane related features are traffic speed and density, queue length at stop lines, waiting time, number of waiting vehicles, origin-destination matrices as primary values. Secondary values are derived statistical features related to the traffic object (average speed, traffic direction, travel time), to the region of acquisition (average density, average traffic speed, average queue length), or to the lane (number of objects). At least the object information can be combined with image information and geo-coded object description to get a user-friendly traffic characterisation with GIS tools.

If objects could be extracted by hardware in the camera system itself, it would not be necessary to transmit the whole image, but only the object information. Image processing algorithms in the sensor system can be implemented in specially designed hardware (e.g. programmable logic) to support real time signal processing.

## SYSTEM REQUIREMENTS

The targets determine the requirements for the complete system. Monitoring traffic implies a signal processing chain for autonomously acquiring and evaluating traffic image sequences, measuring direct traffic related data from optical sensors, combining the extracted information with geographic as well as other information, and characterising the traffic flow in different spatial categories [4]. Not only intersections have to be monitored but also roads with one or several lanes. For those purposes the system has to be reliable (extraction of traffic data even at night and under bad weather conditions) and has to work continuously. Furthermore, it has to identify motorised vehicles (anonymous recognition of cars and trucks) as well as non-motorised road users (pedestrians and bicyclists), and has to track them. A complete overview over the intersection (at least 20 meters in front to 20 meters behind) is necessary and a real-time processing (image acquisition and processing in less than 0.2 seconds, two complete data sets per second) has to be carried out. The direct estimate of traffic flow characteristics in a real world model has to be determined, i.e., components of a geographic information system (GIS) have to be included. The image processing algorithms have to be efficient, robust, and scalable in the region of observation, spatial data models, and information levels. The resolution of the sensors in time and space has to meet these requirements.

With the help of GIS and data bases a sensor fusion should be possible, i.e. synchronisation of time and correlation of space for different images and data. Sensor fusion requires high-speed networking, and signal processing requires outstanding performance. Installation and maintenance costs must be affordable.

The requirements should be taken into account for the design of all parts of the system, which covers the procedures and processes from image signal acquisition via image processing and traffic data retrieval to traffic control.

## SYSTEM ARCHITECTURE

The global structure of the system which can meet the requirements is developed at the DLR (Fig. 1).

The processing chain covers all parts from image signal acquisition up to traffic data generation. There are roughly two different levels of image and data processing, the data base and the GIS module. The first level of image and data processing is called camera node. It includes detection and extraction of traffic objects, geo-coding, and tracking of the objects during their presence in the sensor output. The second level, called intersection node, includes the fusion of traffic objects, the allocation of traffic objects to regions of observation, and the calculation of primary and secondary traffic characterisation parameters.

The data base includes three modules. The first one is an archive for traffic object data, the second one is a data base for special configuration parameters of hard- and software and for the calculated traffic parameters. The third module contains all data suitable to model the road traffic space. Modelling helps to detect critical or dangerous situations which arise very rarely in real traffic but which must be avoided for ethical reasons. In addition, investigations are to be carried out by simulation and in virtual environments. The GIS part of the system is responsible for time management, geometric camera calibration, configuration of observation regions and visualisation of the data. For the camera calibration it is necessary to determine the geometric relations between the actual image and a world model. The used world model is the European Terrestrial Reference System 1989 (ETRS89). The maps of the Universal Transverse Mercator system (UTM) are used.

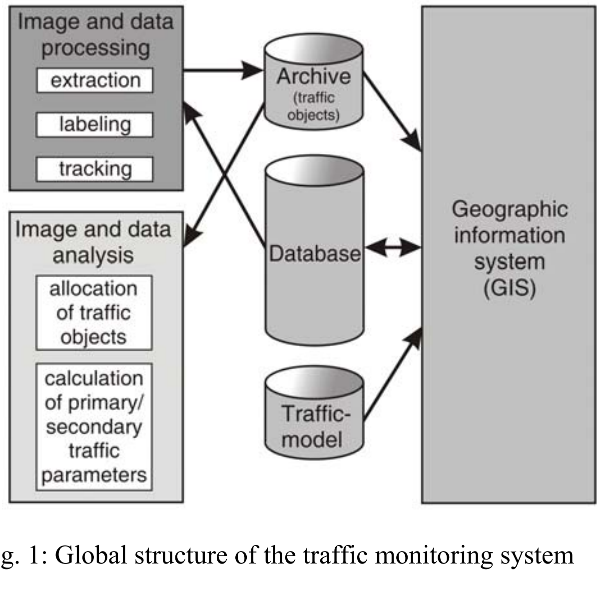

Fig. 1: Global structure of the traffic monitoring system

Visualisation and data analysis are necessary for visual control of processing, modifications for different applications, and comparison with manual extracted data. The data transfer in the system is one- and bi-directional and can be performed via internet or mobile wireless communication structures.

This general structure of a monitoring system for traffic management has to be adapted for special tasks. A configuration example is given in Fig. 2. Dependent on the aim of the application, the types and the number of cameras have to be chosen, the communication structure has to be determined, and the data base and GIS modules have to be established.

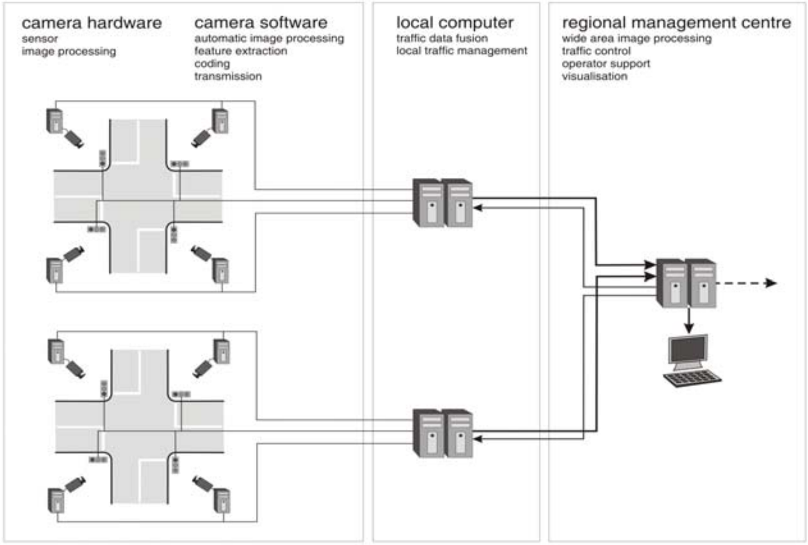

Fig. 2:
Configuration example for two intersections

HARDWARE CONCEPT

The sensor system consists of smart and intelligent sensors with various measurement parameters (radiometric and geometric resolution, spectral sensitivity) which are connected within a network. Such a sensor system should be able to convert the incoming physical signals to digital signals and to process them for special user requirements. The recent advances in computer hardware can provide high computing power with fast networking facilities at an affordable price. The availability of specific solutions at low-cost for general-purpose allows special image processing and avoids some basic bottlenecks. There is an essential need for both flexible software and flexible hardware solutions. One possibility of a flexible hardware design is the implementation of image processing procedures on an field programmable gate array (FPGA). High density FPGA, provided by Altera, Xilinx, and other vendors, include more than one million gates as well as embedded 32 bit processor cores. The Virtex-II Pro Platform FPGA brings together high-density programmable logic, industry standard PowerPC microprocessors, and high-speed I/Os. Truly, this is the digital sandbox which can be used for a big range of image acquisition and image processing applications [6].

With the help of this FPGA several methods of hardware/software partitioning can be investigated.

The design of an image processor commonly starts with a poor software implementation on personal computers or workstations with the help of high-level modelling languages, e.g. MATLAB. The first implementation step is to rearrange and to translate the design to a PowerPC kernel with restricted RAM and ROM and moderate clock frequency. In general, we expect that the software processing time will not comply with the timing constraints of the system, but the power consumption will be considerable low. The second implementation step is to build up hardware accelerator code, located in the programmable logic storage of the FPGA. We found that the memory mapped communication gives the best performance and lowest cost with an FPGA. An optimisation process will find the best combination of hardware and software. The target system will comply both with timing and location constraints and use low power. The opposite design flow - to build up first a pure hardware system and reduce hardware costs by using software - is possible as well, but difficult. Most image processing is currently done in software, not in hardware.

The different functional and non-functional aspects of programmable logic and microprocessor solutions are shown in Table 1. There is still a gap between standard FPGA and microprocessor development tools, but it will be overcome in the future. First systems (e.g. MATLAB) are able to perform a common behavioural simulation and code generation booth in HDL and C language. It is an actual task to find out if the quality of these results will be comparable to the described design flow.

| FPGA | Microprocessor |
|---|---|
| - Configurable and programmable digital logic<br>- Multiple processing units to run tasks in parallel<br>- Hardware-accelerated high-speed tasks<br>- Scalable<br>- Coded in HDL | - Fixed processing units accessed by predefined commands<br>- Greater knowledge, tools, installation base and engineering familiarity<br>- Shorter development time<br>- Lower system costs<br>- Coded in firmware such as C |

Table 1: Functional comparison of FPGA (Xilinx) and microprocessors

The advantage of FPGA solutions is a high degree of parallelism, a flexible structure, low clock frequency, and low power loss. The programmability makes it possible to adapt the structure to the problem (especially the degree of parallelism in the limit of available gates). Furthermore, a lot of hardware code is free available. Algorithms should be selected which are suitable for parallel processing, if it is intended to use FPGA structures for real time signal processing (e.g. FPGA camera control). The degree of parallelism is determined by the amount of hardware resources (gates, slices, modules), so algorithms have to be adapted to these hardware resources for fast operation. It is a challenge to program such a flexible code in a hardware description languages (VHDL) and to verify it by simulation with the help of VHDL models. But if it is done, such codes are highly reusable. The simulation of the code gives an overview on performance, maximal clock frequency, usage of memory structures, space and time consumption. However, the simulation of complex image processing tasks requires too much time. The use of programmable hardware and software allows an early system test without increasing hardware costs. That means that the same platform can be used from the first development step to the whole prototype.

## APPLICATION EXAMPLES

A lot of low and high level image processing algorithms have to be developed to meet all the requirements of an intelligent traffic management system. The performance of the system will depend on the reliable recognition of all road users, their adequate description and the knowledge of how to combine these parameters with information from other sources to solve the problems of traffic management.

In our institutes different algorithms have already been developed and tested concerning different conditions in weather, lighting, and traffic density by varying camera positions, geometrical resolutions, viewing directions etc. Many scientists at DLR and Humboldt-Universität are engaged to contribute to this very complex and challenging field of research. In the following paragraphs three selected examples shall be given. These examples concern the problem of sensor fusion, of extracting and tracking objects, and of evaluating the traffic related air pollution.

### Sensor fusion

Analysing a traffic scene often requires the observation from different viewpoints. Therefore two or more cameras have to be used to watch the full scene. In that case it will be useful to know the spatial relationship between the camera sensors. If the mutual geometric position is known it can help an image processing algorithm to track an object in the images. One kind of linking or fusion of different camera images is made between two optical area sensors working in the visual spectral range (VIS sensor). The spatial relation between the camera sensors can be determined by the so-called epi-polar geometry. This field of geometry supplies a method to map an image point from one image onto an epi-polar line in the other image [5]. This mapping can be calculated pair-wise for every involved camera sensor.

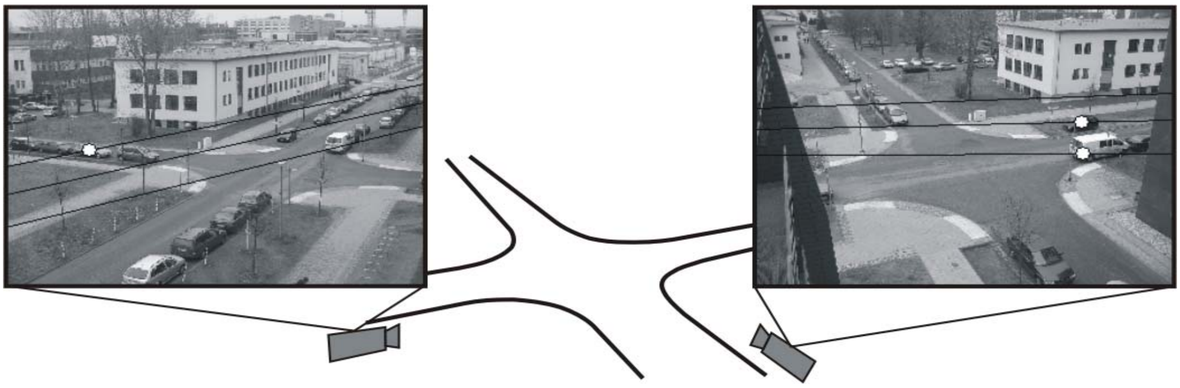

Fig 3: Spatial relation between two images via epi-polar geometry

Fig. 3 shows the epi-polar lines for three selected points − one point for the upper line in the left image, two points for the lower lines in the right image. The selected points mark cars, visible for both cameras, and provide the corresponding epi-polar lines in the respective other image. The lines can be used to select a region of interest for a matching algorithm.

Another way to combine optical sensors is shown in Fig. 4. Here, the spectral range of the observation is additional to the VIS range augmented by a thermal infrared sensor (TIR).

In bad weather conditions and low-light situations the VIS sensor often do not allow meaningful traffic data generation. The TIR sensor is able to show e.g. reflections of the engine or the exhaust on the pavement. The VIS and TIR images will contain different data with different spatial resolution. That is why for an image fusion a temporal synchronisation and spatial correlation is necessary.

Fig. 4: Merged VIS and TIR images

To merge the images in the way shown in Fig. 4, the cameras have to be calibrated by estimating their intrinsic parameters (geometric resolution, focal length) and the extrinsic ones (translation and rotation in world coordinates). The TIR image can be rectified if the parameters are calculated or known. Rectification means the adjustment of the infrared image by a transformation such that this image looks like taken from the position of the VIS camera. This can be done by an (almost) affine transformation if control points in the VIS and TIR images are available.

**Extraction of traffic objects**

Robust segmentation of the images is crucial for traffic surveillance. Objects of interest are pedestrians, motorised and non-motorised vehicles. One well-known method for initial segmentation is the calculation of the difference between the current image and an estimation of the background. In general, the algorithms for background estimation have to deal with a vast number of different lighting conditions. Rapid changes of image intensity due to clouds, rain or automated exposure control of the camera itself have to be taken into account.

All these problems have to be addressed, otherwise the background update will be trapped in a vicious circle: false background estimation will lead to false segmentation. False segmentation will lead to a false update of the background image. Fig. 5 illustrates a segmentation process. After the background image was initialised the difference image between the background and the current image is calculated using the HSV colour model. Differences are calculated independently for each channel, ignoring the V channel. An adaptive threshold is applied to the difference images. The two resulting binary images are merged with an logical OR operation.

A connected component analysis and the calculation of the convex hull of each object provides the traffic objects. The set of convex hulls is also used for masking the regions that are excluded from the update of the background image. Image processing also includes the search for shadow, histogram calculation and morphological operations. Tracking of objects in an image sequence is done with Kalman filtering. This approach allows the tracking of occluded objects. Tracking is a necessary task for instance to determine the origin-destination relations at intersections.

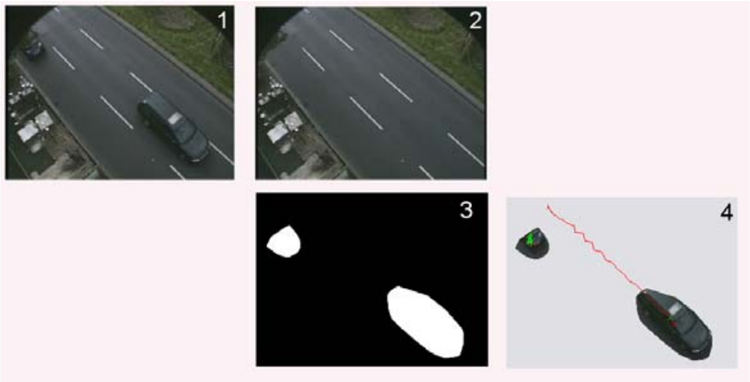

Fig. 5: Extraction and tracking of traffic objects

**Pollution prediction**

Traffic parameters such as the number of trucks and cars and their average speed can be used to estimate the traffic related air pollution. Good prediction results require the classification of car types, especially of trucks, and the characterisation of the traffic situation. Fig. 6 illustrates the classification process for trucks.

Fig. 6: Classification process of trucks

After segmentation the front of each truck is extracted and normalized. Then potential positions of the manufacturer logo are searched. The two-dimensional cross correlation provides a similarity measure for truck classification.
In Berlin traffic related air pollution is acquired with a network of sensor units which are spread over the whole city. The concentrations of NO, NO2, NOX, SO2, CO and PM10 are measured. A camera was installed above one of the sensor units to determine up to which degree the concentration can be estimated by simply counting cars and trucks. The first step was to look for a possible temporal shift between the data. As shift index the maximum of the normalized discrete cross correlation function was calculated. Then the Pearson correlation coefficients for the time-shifted curves were determined. Table 2 shows the correlation coefficients between air pollutant concentration and the number of trucks or the number of all vehicles, respectively.
The value of correlation indicates that the number of trucks is a better measure for traffic related air pollution than the number of all vehicles. However, additional parameters should be included. An appropriate model includes weather information, information about the sensor position and specifics of each estimated concentration. The information about the truck type can be used to incorporate type-specific emission characteristics. The amount of pollution is also sensible to the traffic situation. The consideration of average speed will allow to apply the appropriate pollution model. Traffic situation and vehicle specific models are public available.

| Air pollutant | correlation coefficient (5 min sum of trucks) | correlation coefficient (5 min sum of all vehicles) |
|---|---|---|
| $SO_2$ | -0.29 | 0.01 |
| NO | 0.22 | 0.10 |
| $NO_2$ | 0.57 | 0.03 |
| $NO_X$ | 0.27 | 0.10 |
| CO | 0.43 | 0.01 |
| PM10 | -0.03 | -0.10 |

Table 2: Correlation coefficients between air pollutant concentration and the number of trucks or the number of all vehicles, respectively

## CONCLUSION

Traffic monitoring by optical sensors provides the capability of real-time surveillance of large areas. The use of complementary sensors (stereo camera, IR and VIS sensors) provides a variety of images which can be processed to extract features and to track all kinds of observed objects. There are still problems with synchronising the various images or finding spatial correlations in real-time. Future developments should deal with scalable procedures for time-consuming tasks and with methods for an optimal partitioning of hardware and software implementation of the developed algorithms.

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