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day and night image processing, stochastic process, fundamental diagram, spatial mean velocity of traffic stream, traffic density

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A METHOD FOR AUTOMATIC TRAFFIC-STATE IDENTIFICATION FROM THE DRESDEN LIVE-CAMERA SYSTEM

The presented paper wants to describe a new solution for the problem of real-time identification of the traffic state from live-camera images based on the analysis of stochastic signals. By using the Dresden Live-Camera-System which is providing real-time information about the traffic state on 22 focal points one is able to analyze a wide range of image types under different and severe conditions. At the present time 22 Live-Cameras are in use from Pirna in southeast until the north of Dresden and can be surveyed at "www.intermobil.org".

METODY AUTOMATYCZNEJ IDENTYFIKACJI STANU RUCHU W DREZDEŃSKIM SYSTEMIE MONITORINGU

Artykuł opisuje nowe rozwiązanie dla problemu identyfikacji w czasie rzeczywistym stanu ruchu z obrazów pochodzących z kamery w oparciu o analizę sygnałów stochastycznych. Poprzez wykorzystanie drezdeńskiego systemu monitoringu, który dostarcza informację w czasie rzeczywistym o stanie ruchu z 22 punktów, istnieje możliwość analizy szerokiego zakresu typów obrazu w różnych warunkach. Obecnie 22 kamery znajdują się w eksploatacji w Dreźnie i mogą być śledzone na stronie internetowej www.intermobil.org.

1. INTRODUCTION

Video Detection Systems allow cost effective real-time detection of traffic state on focal points. The operation of such systems leads to some advantages. At first the systems enable the information about the occurrence and the cause and effect of incidents. The second advantage it the wide-range capability. Therefore the surveillance and detection is faster and more efficient compared to inductive loops. The measurement spots can be modified with less effort and expenses. The third advantage is the saving of costs. The amount of virtual sensors per camera is only limited by the hardware performance. In the last 5 - 10 years a lot of

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systems for video-based traffic state identification are developed. Systems like Vantage from Iteris [3], the Traficon Video Image Processor [2] and the Auto Scope System from Data Collect [1] are established. A lot of publications [4]-[17] dealing with further refining of these systems, and development and application of new methods. Common used techniques as pattern- and edge recognition have disadvantages in the case of screening of vehicles in line-ups. The present work wants to contribute a new solution based on the analysis of stochastic signals. Figure Fig.3 shows two virtual sensors as they are used in the presented method. The Dresden Live-Camera-System includes 22 focal points until now. This count of images overextended the observer so that automated selection is necessary. On the other hand one can not receive the velocity, trend and travel time from live-camera images from traffic light controlled lanes. But these are the interesting values for traffic-management and private users. Therefore a new approach for tackling this problem will be introduced in the following paper. It is strived the development of a robust method which is working in real time and can be implemented in a camera computer. The following figure illustrates this aim.

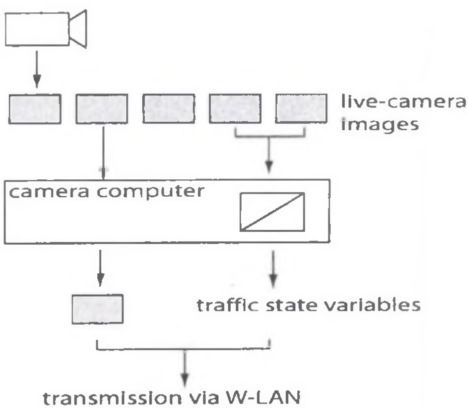

Fig.1. The aim of the presented work

2. METHODOLOGY

2.1. GETTING IMAGES

The used camera is a Colour-CCD-Camera (Sony FCB-IX47) with 18-times optical and 4-times digital zoom. The focal length is from 4.1 mm to 78.8 mm. The angle of view varies from 2.7° to 48°. The current image is stored in the camera computer. When a new image was stored the interpretation of the image starts event controlled. The present image will be replaced with the following one. The time interval between two images is about 2 seconds. For the purpose of velocity determination the data from two successive images will be evaluated. For the computation of traffic density and empty road detection only the present image is used.

2.2. SIGNAL GENERATION AND PRE-PROCESSING

The signal generation is based on grey or colour tones. The area in the image to be evaluated is described by a poly-line. This is called measurement line. The grey tones or r-g-b colour tones of the pixels on the measurement line create a stochastic signal. The grey/colour tones are a stochastic variable defined from 0-255. They are stochastic because number, properties and places of the vehicles are not predictable. This variable with the pixels index as argument creates a stochastic signal - the grey tone function. It is representing the vehicles in the observed area spatial and temporal. The successively determinated grey-tone functions form the stochastic process "grey tones on the measurement line". Caused by the variable conditions this process is non-static. It will be transformed into a static process by centring on the arithmetic mean value. The camera position causes a distortion of the image contents. This distortion is also represented in the grey-tone function and will be transformed in a non distorted function. Now we have discrete, mean value free stochastic signals. These signals realise a discrete static stochastic process. The work up of the signals allows methods of the theories of stochastic processes.

2.3. SIGNAL PROCESSING

The signal processing consist of three parts. The determination of the mean spatial temporal traffic stream velocity, the determination of the traffic density and the determination of the state: lane occupied/ non occupied. The following sections illustrate the methodology of these algorithms.

2.3.1. VELOCITY

The determination of the velocity is based on the grey-tone functions of two following images. These functions are called x_n and y_n. where n means the index of the pixels. With these two functions we have a two-dimensional stochastic process. The description of this process is done as usual by distributions and moments. In contrast to familiar considerations the signals are path-dependent, not time-dependent. Therefore the time t as argument is replaced by n or m:

$$n = s / \Delta s \tag{1}$$

Where s means the length of the measurement line and Δs means the length of a single pixel. There are $f(x_n)$ and $f(y_n)$ the probability distribution density functions of the discrete stochastic functions x_n and y_n. In order to get information about the relation between the values of the signals the cross-correlation function is calculated.

$$R_{xy}((x-\mu_x)(y-\mu_y)) = R_{xy}(m,n) = \sum_n (x_m - \mu_x)(y_n - \mu_y) f(x_m) f(y_n) \tag{2}$$

The precise knowledge about the distribution functions is not available. Therefore the exact cross-correlation function will be replaced by an estimated function while the ergodicity is assumed. The estimation is unbiased when the process is static and the mean value is known.

Therefore the estimated mean value is used.

$$\hat{\mu}_x = \frac{1}{M}\sum_m x_m \tag{3}$$

$$\hat{\mu}_y = \frac{1}{N}\sum_n y_n \tag{4}$$

Moreover:

$$n = m - \rho \quad and \quad M = N. \tag{5}$$

Now one gets the cross-correlation function (CCF)

$$\hat{R}_{xy}(\rho) \approx \frac{1}{N-\rho}\sum_{n=1}^{N-\rho}(x_n - \hat{\mu}_x)(y_{n+\rho} - \hat{\mu}_y) \tag{6}$$

The displacement in pixels means ρ. The validity proof is done in [24] page 230 and next. The principle of velocity determination is explainable now. An important property of the CCF is the ability of showing the identity of signals depending on there arguments. The major equality corresponds with the maximum of the CCF. In our case the arguments are the index of pixels on the measurement line. That is why the CCF is able to report the similarity of x_n and y_n depending on there displacement. From this it follows that the movement of vehicles which are represented in x_n and y_n can be recognized by the CCF. After calculating the CCF with the grey tone functions x_n and y_n reports the maximum of the CCF the movement of the vehicle stream in pixels. Knowing the resolution (PMS) of pixels and the time space (Δt) between the images one gets an estimated velocity of the vehicles stream between the record of the two images.

$$v = \frac{\max(\hat{R}_{xy}(\rho))}{\Delta t} PMS \tag{7}$$

The maximum of the measurable velocity is depending on the count of pixels, the resolution of the image and the time space between recording the images. The count of pixels and the solution are situated in the denominator of (7). Therefore we have depending on the situation a minimum count of pixels. In other words: The observed lane must present a minimum length. As a result the time Δt has a maximum value. Deficits of the denominator values can be adjusted by the nominator value.

2.3.2. TRAFFIC DENSITY

At first the grey tone function will be filtered. The filter replaces signal components which are not representing vehicle information with zero values. Based on the assumption that signal parts less then a fraction of the maximum of the grey tone function don't contain information about vehicles they can be replaced by zero values. The size of this fraction is the only parameter of the filter. After filtering the signal the number of zero-crossings is counted. This count is depending on the amount of vehicles in the observed area. By scaling it one will get an estimation of the real count of vehicles. This can be easily converted into the traffic density. The calculation of the fraction parameter is done when vehicles are present. Therefore different lightning conditions are respected.

2.3.3. LANE OCCUPATION

The cross-correlation reports a velocity of zero in two cases: the first one is the traffic congestion. The second one is the empty lane. To distinguish these two cases an extra algorithm is necessary. The idea is based on the observation that vehicles cause more colours in the image than the empty lane has. It can be shown that the r-g-b-colours are correlated so that one can use only two of them. The following figure shows the result of an investigation of this idea. Figure Fig.2-a contains the green and red values of a grey tone function describing vehicles on the lane. Figure Fig.2-b shows the same information while the lane was empty. Obviously there is a difference. To be able to calculate some things the cluster of points are transformed into ellipses (Fig.2-c and Fig.2-d). Now we can use the length of the big axis of the ellipse as information whether the lane is occupied or not. The length of the ellipses big axis is specified by extensive statistical work which is not introduced here.

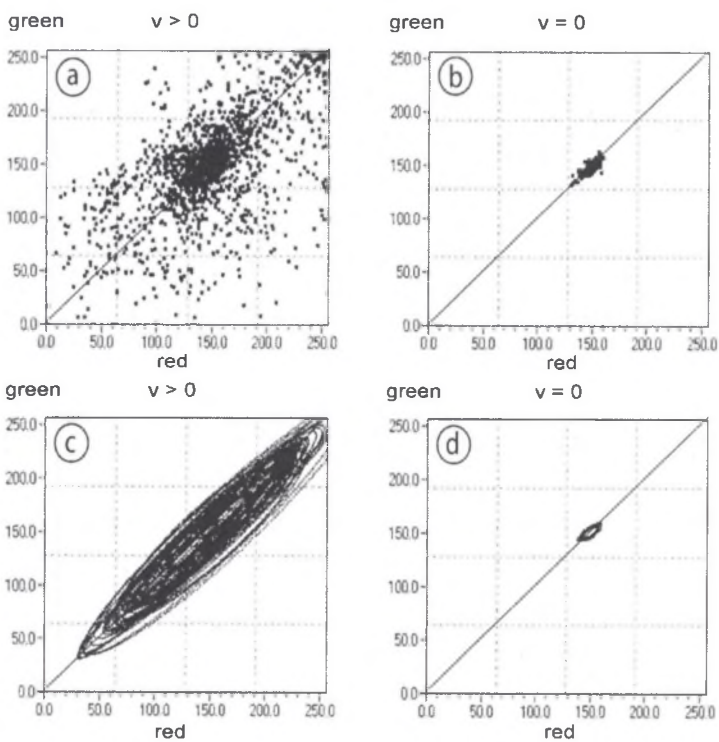

Fig.2. Colour dependence

3. EXPERIMENTAL TEST

After scrutinizing the method with in advance stored image-sequences since May 2003 the algorithm is implemented on four locations in Dresden. One of the selected points is shown in Fig.3. The following results investigated on May, 11^{th} 2003 on this location. There two traffic congestions detected on sensor 0.

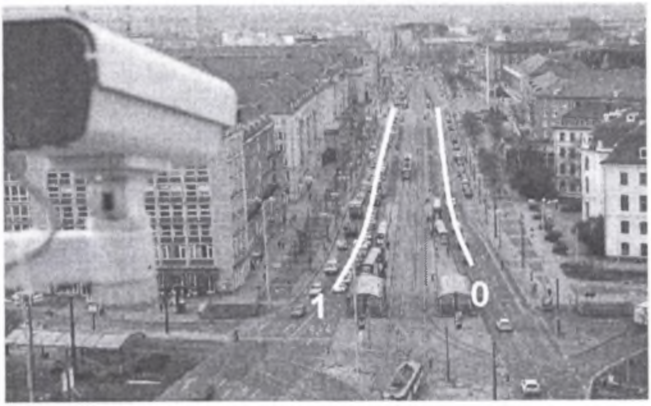

Fig.3. Test scene

The method enables distinction of different traffic states such us free flow, heavy flow, stop and go. Determination of single vehicle data or vehicle classification is not possible and purchased by robustness of the method. The red curve shows the calculated velocity of the traffic stream after filtering it. Conditioned by different influences the raw data swaying around a mean value. Therefore the filtering of the data is necessary. On the other hand traffic lights cause a stop and go behaviour which must be eliminated fort the purpose of traffic state identification by the same filter. It is a digital IIR-Filter with a critical frequency of 0.003 Hz. That causes an elimination of signal components less then 5 min cycle duration.

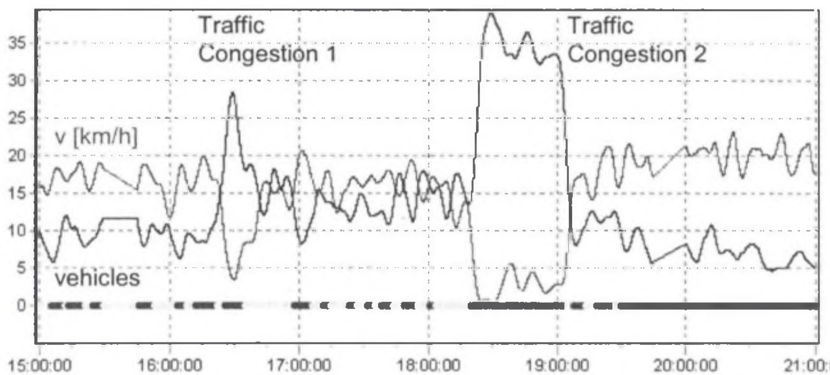

Fig.4. Calculated velocity, traffic density and level-of-service

The maximal velocity observed is about 20 km/h. This is plausible because of permitted 30 km/h. The difference between 20 km/h and 30 km/h indicates the influence of the traffic light and illustrates that we calculate a spatial and temporal average velocity. Dividing this maximal velocity in to three parts enables to recognize level of service. The result is shown in the horizontal yellow/green/ red line. The calculated course of the velocity shows a sag in level of service red below 5 km/h. Confirming of the two traffic congestions was done by comparing with the stored live camera images. The calculated spatial and temporal velocity of the traffic stream is hardly understandable for drivers because there is no obvious relation to the speed of a single vehicle. Therefore the travel time also will be calculated. The relation between velocity and traffic density can be described by different models. There are two common features of all these models. The increase of density causes a decrease of velocity and the maximum density is reached for a velocity of zero. In order to get the corresponding model for the observed lane the velocity is shown in relation to the traffic density in Fig.5.

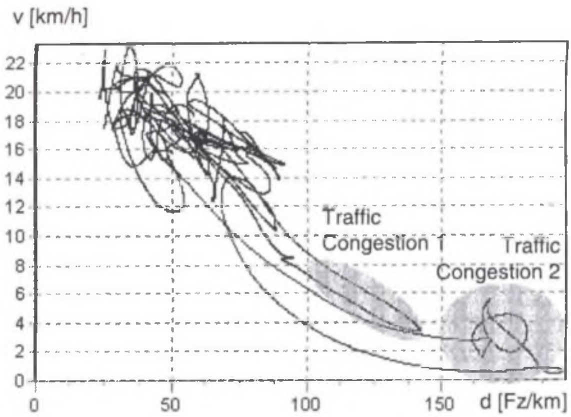

Fig.5. Velocity/density model

The resulting graph comes out in a qualitatively and quantitatively right manner. Remarkably the graph is a closed curve with hysteresis related transitions between the traffic states. Another type of a traffic state model is the so called fundamental diagram. This is the graph with the occupancy [vehicles/time] on the ordinate and traffic density on the abscissa. The occupancy q is calculated with the continuous equation

$$q = v \cdot d. \tag{8}$$

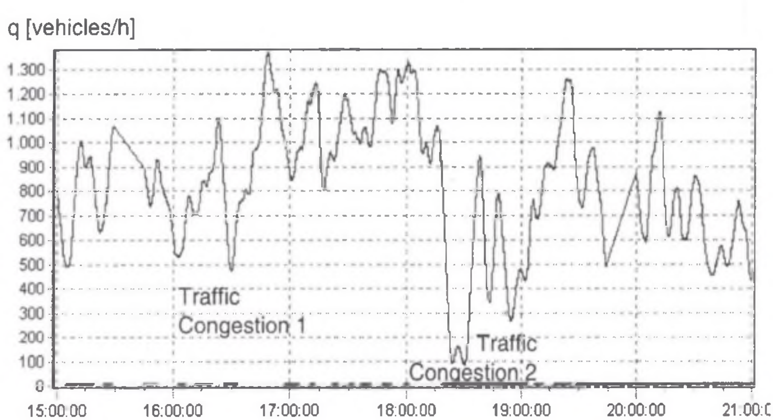

Fig.6. Calculated occupancy

At this the used v and d values must be temporal and spatial values what is complied. Fig.6 shows the calculated occupancy. The fundamental diagram has the following lookout.

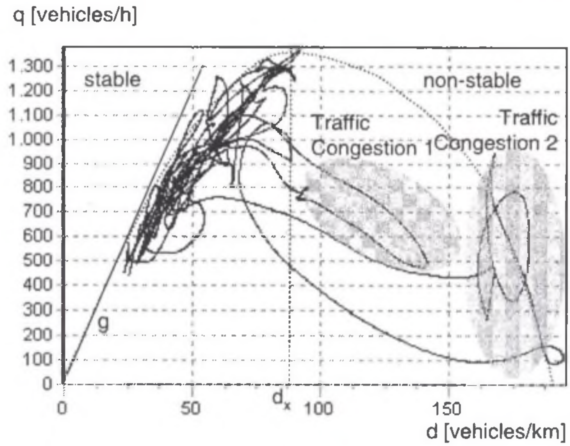

Fig.7. Fundamental diagram

The dotted curve is showing the possible form derived from the Greenshild model. The maximum of the curve is situated on the density d_x . This density divides the q/d plane into two parts of the stable (left) and non-stable (right) traffic flow. Remarkable are the two traffic congestions in the non-stable area. Increase of straight line g means the free flow velocity and was calculated to 24 km/h.

4. CONCLUSIONS

This paper introduces a new approach for automatic image analysis for traffic-state identification. The methodology is based on the evaluation of stochastic signals derived from grey tones of measurement lines defined on the live-camera image. The outcome of the identification is a spatial-temporal traffic stream velocity, traffic density and information containing lane occupied/ not occupied. The data are filtered by a digital IIR-Low Pass to eliminate influences from traffic lights. Moreover a level-of-service, travel-time and trend information can be derived. The results are discussed on the fundamental diagram and the speed/density relation. These days the algorithm is implemented on four focal points of the Dresden Live-Camera-System. Future work will include application on motorways.

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