DETECTION AND TRACKING OF VEHICLES BASED ON THE VIDEOREGISTRATION INFORMATION

V.N. Kopenkov
IPSI RAS, Samara State Aerospace University
Lukacheva 39B, (443086) Samara, Russia
vkop@geosamara.ru

V.V. Myasnikov
IPSI RAS, Samara State Aerospace University
Lukacheva 39B, (443086) Samara, Russia
vmyas@geosamara.ru

ABSTRACT

This paper describes the technology of detection and tracing vehicles on the sequence of images based on digital video stream analysis in the real-time mode. Such technology can be used for car identification, license plates recognition, and for defining of car traffic parameters: the cars speed and average speed of car traffic, the traffic density, et cetera. One of the main advantages of the presented technology is the simplicity of realization and the possibility of making a cheap solution based on it (cheap camera and a ordinary PC), in contrast to most of the specialized solutions with a high price, and requirements of high-performance hardware components as usual.

Keywords

objects detection and recognition, speed estimation.

1. INTRODUCTION

The tasks of image processing and signal analysis need to be solved in different fields of human activity [Luk01a]. Due to evolution of computer equipment we can realize the tasks which could not be implemented in practice some years ago. One of them - is the processing of video streams in real-time [Sta00a, Mya01a]. Such a process is usually required in teleconferencing systems, security, tracking and other video-analysis systems. Another trend of research in video stream processing technology evolving today, is the analysis of traffic flows based on videoregistration data [Luk01a, Cas00a].

The simple transfer of videos to the operator monitor is ineffective for videostream analysis in real-time. Initial videodata have to be preprocessed to improve the efficiency and quality of decisions of such tasks. It requires the use of algorithms of automatic track changes appropriate for finding, recognizing and analyzing various objects on the images and finally to inform the operator about any unusual situations.

Most of the traditional methods of traffic video information analysis are based on the selection and detection of some specific areas on the image and further tracking of these selected areas on the following frames. Such decision can often be functional but it`s not effective due to computational complexity, not always high precision, and strong dependence on the characteristic regions. Therefore it is unacceptable for the described task solution.

2. TASK DEFINITION AND THE VIDEO RECEIVING MODEL

The hardware

The hardware complex, which provides the function of the offered technology, should consists of the following components: data source (video camera); device of transferring an input signal to a PC - special video capture card or video card with a digital/analog input interface; PC for data processing and storage.

Special database (DB) containing images of all detected vehicle`s were created for the testing of proposed information technology, as well as the appropriate software tools to work with this database. The database consist of *1041* images of vehicles detected in the video stream, were filmed on the road. DB store the following information about vehicles:

- the centre of the vehicle license plate (LP),
- the size of the vehicle LP - vertical/ horizontal,
- the LP tilt angle is relative to the horizontal,
- the existence of the vehicle LP,
- the visibility parameter of the LP on the image,
- the type of the vehicle LP,
- the content of the LP - registration number,

the BMP filename, with the image of the vehicle.

Video recording model

As it is shown in Fig.1 – the video camera is mounted at a height h, and L_2 – is a distance to the nearest visible point (i.e., the end point of the area of tracking vehicle). L_1 – is a distance to a farthest visible point D. The optical axis of the camera is OB.

The plane of the video recording is perpendicular to the optical axis of the camera *OB*. Let it be located on the point *EC*. The number of rows in matrix - N_1. In this case the following expressions are correct.

$$t = |OC| = \sqrt{h^2 + L_2^2}, \beta_1 = \arctan\left(\frac{h}{L_1}\right), \beta_2 = \arctan\left(\frac{h}{L_2}\right) \quad (1)$$

$$\gamma = \beta_1 - \beta_2,\ d = |EC| = 2t \sin(0,5 \cdot \gamma).$$

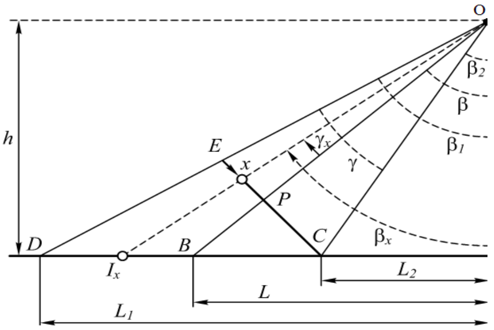


Figure 1. Geometrical model of video recording.

The video processing model can be represented as it follows: an video input module generates digital images which are based on the incoming video stream. After then those images are used as an input information for the vehicle detection module. According to the dynamic changes on a digital image a decision about presence or absence of the vehicle is taken. The image with the detected vehicle is used as an input for the tracking and speed determination module. Data about vehicle speed and the image of detected vehicle, have to be presented to the operator.

3. AN ALGORITHM OF VEHICLES DETECTION AND TRACKING

To determine whether the vehicle is presented on a digital image, there are two images used: current image and the current background component. The background component image is calculated as:

$$S_i = \alpha X_{i-1} + (1-\alpha) S_{i-1}, \quad (2)$$

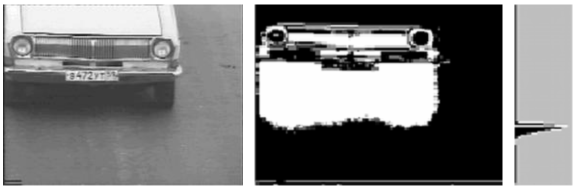
S_i – current background picture; X_{i-1} – image on the previous step; S_{i-1} – background picture on the previous step; α – coefficient (small enough), which determines the rate of change of the background component and it depends on the presence of absence of the vehicle on the current frame.

Such representation of the background component allows to accumulate changes of the background component and the system can automatically adjust to change in the light of the scene (day, night) and weather conditions (snow, rain, cloudy, sunny).

The image X_i can be presented as:

$$X_i = U_i + V_i, \quad (3)$$

U_i – background component (stationary); V_i – figure of vehicle (background changes is assumed as noise).



a) b) c)

Figure 2. Vehicle detection.

To detect the vehicle on the image we can produce logical subtraction X_i (the current frame - fig. 2a) of S_i (current background). The result is the background component changing area. After the threshold processing obtain a mask representing the binarized region of changes - "trace" of the vehicle (Fig. 2b).

Parameter α determined the speed of background component changing depends on the mask:

- if the proportion of the mask more than 5% of the image size (there is vehicle in visible area), the coefficient α reduced by 50 times, so as not to accumulate noise on the background component;
- If the same proportion of the mask less than 5% of the image size, the coefficient α given back to the original value if the mask part more than 5%.

The exception of this rule is the "systems stabilization time" - time of setting up of background component and weather condition when α coefficient is constant regardless of the proportion of the mask on the image, until the difference between image and the background on the adjacent steps is less than a threshold.

When a proportion of the mask will be more 15% of the image size, the process of vehicle detecting and tracing is starting. And following algorithm is used:

1) calculate a mathematical expectations array in rows of the current mask; recalculate its values:

$$a_i^{new} = a_{i-k} - 10 a_{i+k},\ \ k = 1...5;$$

2) detect the max of this new array. According to previous transformation the max positions corresponds to the maximum difference of brightness on the mask (area under the bumper) - see. Fig. 2c.;

3) the tracking of the vehicle on the image is finishing when there is a "jump of the max" (max is not found) or if the proportion of the mask < 15%.

4. AN ALGORITHM OF VEHICLES SPEED CALCULATION

To determine the vehicle speed the position of max value of the brightness difference array is used. These values received from two frames - at the beginning and at the end of vehicle tracking and used with the corresponded measurements of the frames time. If this frame is the first frame of the vehicle tracking process, then we save the coordinate $i_1^{\max}$ of the max value and the time t_1 as start parameters of the vehicle tracking. If this frame is the last frame of the vehicle tracking, then we save the coordinate $i_2^{\max}$ of the max value and the time t_2 as a vehicle tracking termination parameters. After than speed can be determined as:

$$v = \frac{l_x(i_1^{\max}) - l_x(i_2^{\max})}{t_2 - t_1}, \quad (3)$$

where $l_x(i_1^{\max})$, $l_x(i_2^{\max})$ – the actual distance to the vehicle from the recording device.

Considering that the brightness difference accounts to area under the bumper of the vehicle on the picture the speed estimation will be the most accurate in the case of precise observance of the receiving video system installation parameters (height, distance and camera position). In this case the camera mounting height in relation of the vehicle fixation point (brightness difference) is constant. At the same time when we use LP of the vehicle for the speed determining by finding and tacking the LP position on the pictures - the accuracy of this estimation can be considerably lower. This occurs because of different height of LP mounting towards to the camera position (bumper, radiator frame, bus, truck, etc.). Taking into account the geometric model of the video recording presented above the following algorithm is used for the vehicle speed estimation.

Denote by i the required row number on the recorded image and then corresponding to it point location on the segment EL, which is equal the distance from a point x to E, can be calculated as: $x = i\dfrac{d}{N_1 - 1}$.

At the same time actual distance l_x on the plane AD from the point A is defined as $l_x = h \cdot \tan(\beta_x)$, where the angle value β_x can be represented as:

$$\beta_x = \beta + \gamma_x,\ \beta = \frac{\beta_1 + \beta_2}{2},\ \gamma_x = \arctan\left(\frac{(d/2) - x}{|OP|}\right).$$

$$|OP| = t\cos\left(\frac{\gamma}{2}\right),\ \gamma_x = \arctan\left(\left(1 - \frac{2i}{N-1}\right)\tan\left(\frac{\gamma}{2}\right)\right).$$

The distance l_x can be executed in three steps:

<u>1 step</u>: calculate β_1 and β_2 by using (1):

<u>2 step</u>: calculate β_x:

$$\beta_x(i) = \frac{\beta_1 + \beta_2}{2} + \arctan\left(\left(1 - \frac{2i}{N-1}\right)\tan\left(\frac{\beta_1 - \beta_2}{2}\right)\right) \quad (5)$$

<u>3 step</u>: calculate $l_x(i)$: $l_x(i) = h \cdot \tan(\beta_x(i))$. (6)

To accelerate the calculating process the $l_x(i)$ values can be tabulated for all values of $i = \overline{0, N-1}$.

In a situation, when the analyzed point is located at some height h_0 (relative to the road), the expressions (1), (5), (6) can also be used for calculating of the actual distance to the object after replacing the values L_1, L_2 and h to the values L_1', L_2' and h':

$$h' = h - h_0,\quad L_1' = h' \cdot \tan(\beta_1),\quad L_2' = h' \cdot \tan(\beta_2). \quad (7)$$

Obtaining information about the horizontal arrangement of the tracking object is only possible in case of precisely known distance to the camera. Suppose that this was performed, we know the actual shooting distance from the object to the camera - l_x (see. Fig. 3). In this case, we can obtain the equation:

$$w_x = l_x \frac{W_2}{L_2},$$

W_2 – width of the tracking area on the distance L_2.

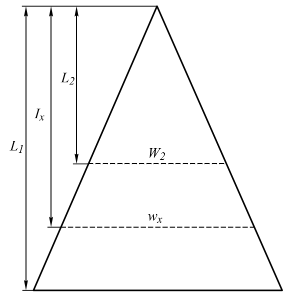


Figure 3. Geometrical model of vehicle tracking area.

Note that the following equality should be performed for the boundaries of digital image:

$$w_x = -\frac{W_2}{2}, if \begin{Bmatrix} j_x = 0 \\ l_x = L_2 \end{Bmatrix};\ w_x = +\frac{W_2}{2}, if \begin{Bmatrix} j_x = N_2 - 1 \\ l_x = L_2 \end{Bmatrix},$$

N_2 – number of cols in matrix of registration, j_x – the desired pixel, the expression for the horizontal coordinate of the registered point is obtained:

$$w_x(j_x) = W_2 \cdot \left(\frac{j_x - (N_2 - 1)/2}{N_2 - 1}\right). \quad (8)$$

In a situation, when the analyzed point is located at some height h_0 (in relation to the road surface), the expression (8) can be used after replacing the value W_2 to the value W_2', and note that $L_2 = h \cdot \tan(\beta_2)$,

$\dfrac{W_2'}{W_2} = \dfrac{|OC'|}{|OC|} = \dfrac{\sqrt{h'^2 + (L_2')^2}}{\sqrt{h^2 + (L_2)^2}}$, the (8) can be presented:

$$w_x(j_x, h_0) = W_2 \cdot \frac{h}{h - h_0}\left(\frac{j_x - (N_2 - 1)/2}{N_2 - 1}\right). \quad (9)$$

5. EXPERIMENTAL RESEARCH

Vehicle detection on a videostream

Experimental researches were conducted on the basis

 ISBN 978-80-86943-67-1

of the analysis of real traffic flow recorded movie, which represents a collection of video clips with different seasons, day-time and weather conditions.

Recording conditions	Vehicle missed	Detected too late	Multy-detection		
			2	**3**	**4**
Day (10 min.)	4	1	9	1	0
Night (20 min.)	8	22	16	1	1
Winter (9 min.)	10	0	13	2	1
All (39 min.)	*22*	*23*	*38*	*4*	*2*

Table 1. Statistics of detection of moving vehicles.

In case of the night video the number of missed and late detected vehicles is exaggerated, because this video consists of many small clips. The system has not enough time to tune on the background component changing. The probability of the vehicle detection is about 0.95 and the probability of missing - 0.05. There is a slight dependence on the shooting conditions of night, day, winter, etc. The probability of false detection of a non-existent vehicle is equal to 0. Some vehicle can be marked more the once.

Vehicle speed estimation

At the moment, there is no way to make an accurate assessment of the efficiency of vehicle speed estimation algorithm due to the fact that precise data of vehicles speed is not available (from the patented device for the velocity determination) for the experiments. The results of expert evaluation of the vehicle speed corresponds to the expected values. The error estimation is about 5-10%. Necessary to obtain a traffic flow video with accurate information of each vehicle speeds, the future investigation of the efficiency of the algorithm of vehicle speed determination, is as well as calibration of the parameters.

6. PARAMETERS OF TRAFFIC FLOW

The parameters are typically correlated to traffic flow [Gas00a, Cas01a] is a speed, density and the actual volume of traffic flow. The flow velocity v means the average speed of the vehicle (for the analyzed period). The density ρ - is the number of vehicles per area unit, the volume of the flow q is the number of vehicles per unit of time Assume that, T – is the duration of the interval of an assessment accumulation, for which at a particular time t_0 K vehicles with the parameters $\{t_k, v_k\}_{k=0}^{K-1}$ are registered, where $t_k \in [t_0 - T, t_0]$ – the time of particular vehicle detecting, v_k – speed of this particular vehicle. In that case the estimations of the required parameters may be determined by formulas:

$$\hat{v}(t_0) = \frac{1}{K}\sum_{k=0}^{K-1} v_k \ , \ \hat{q}(t_0) = \frac{K}{T} \ , \ \hat{\rho}(t_0) = \frac{K}{\hat{v}(t_0) T W_2 \left(\frac{L_2 + L_1}{2L_2} \right)} .$$

7. CONCLUSIONS AND RESULTS

The paper presents an *efficient technology* that allows to solve the following tasks in a real-time mode:

– *detect the vehicle on a videstream,*

– *evaluate the velocity of the vehicle on the image regardless of the presence of the vehicle LP,*

– *determine the density of traffic flow on the basis of the estimation of individual vehicle parameters.*

The main advantages of this technology are:

1. A vehicle`s detection and tracking (also as speed estimation) based on the detection of the vehicle itself but not of the vehicle LP (the problem of detecting the vehicle without LP can be solved).
2. The adaptive tuning of the algorithm parameters allows to detect the vehicle efficiently, regardless of changing weather or lighting conditions.
3. The computational efficiency of the developed algorithms in very high.

The perspectives of future works involve the specification of the model and to configure the algorithm of the speed estimation on the base of the real data on the vehicle speed. One more direction of the research is the development of techniques for the detection and recognition of LP on the vehicle.

8. ACKNOWLEDGMENTS

This work was financially supported by the Russian Scientific Foundation (RSF), grant no. 14-31-00014 “Establishment of a Laboratory of Advanced Technology for Earth Remote Sensing”.

9. REFERENCES

[Luk01a] Lukyanitsa A. // Digital processing of video images // A.A. Lukyanitsa, A.G. Shishkin AG – M.: ISS Press, 2009. – 518 p. – (In Russian)

[Sta00a] Stauffer, Ch. Learning Patterns of Activity Using Real-Time Tracking Pattern Analysis and Machine Intelligence / Chris Stauffer, W. Eric L. Grimson // Pattern Analysis and Machine Intelligence, IEEE Transactions on. – 2000, Aug. – V. 22, Issue 8. – P. 747-757.

[Mya01a] Myasnikov, V.V. Method for detection of vehicles in digital aerial and space remote sensed images // V.V. Myasnikov // Computer optics. – 2012. – №36(3). – P. 429-438 – (In Russian)

[Gas00a] Gasnikov, A. Introduction to Mathematical Traffic Flow Modeling / A.V. Gasnikov, S.L. Klenov, E.A. Nurminski, Ya.A. Holodov, N.B. Shamrai // Moscow: MFTI, 2010. 362 p..

[Cas01a] Cascetta, E. Transportation Systems Analysis: Models and Applications V.29. Springer Optimization and Its Applications, 2009. 760 p.

[Kop01a] Kopenkov V.N. The estimation of the traffic flow parameters based on the videoregistration data analysis /Computer optics. 2014. №38(2). P. 351-355.