Vehicle Detection and Counting System for Real-Time Traffic Surveillance

Boris A. Alpatov, Pavel V. Babayan, Maksim D. Ershov
Department of Automation and Information Technologies in Control
Ryazan State Radio Engineering University (RSREU)
Ryazan, Russia
aitu@rsreu.ru

Abstract—**In this paper we are considering road situation analysis tasks for traffic control and ensuring safety. The following image processing algorithms are proposed: vehicle detection and counting algorithm, road marking detection algorithm. The algorithms are designed to process images obtained from a stationary camera. The developed vehicle detection and counting algorithm was implemented and tested also on an embedded platform of smart cameras. The results of experimental research of proposed algorithms are presented.**

Keywords-traffic surveillance; smart cameras; video analysis; image processing; object detection; background subtraction; line detection

I. Introduction

The emergence and actualization of various tasks in the field of transport analytics are associated with constantly growing number of vehicles on roads, which leads to a significant increase in economic and social costs. Insufficient traffic safety and traffic jams are major problems in cities around the world. A solution of these problems is very expensive in the face of growing pressure on transport infrastructure.

One possible approach is the application of adaptive traffic control systems placed in streets of a city. The traffic control systems not only reduce delays and congestion but also solve other problems:

- Detection of accidents and vehicles stopped in wrong space [1].
- Compliance monitoring and registration of traffic violations.
- Obtaining of traffic flow statistics.

This work is devoted to solving such problems of traffic control systems as the detection and counting of passing vehicles. In addition, the road marking detection algorithm is proposed. The solution of these problems is considered for a stationary video camera installed above the road surface.

The requirement to implement image processing algorithms on an embedded platform of intelligent video cameras was taken into account when developing these algorithms.

The structure of vehicle detection and counting system is presented in Fig. 1.

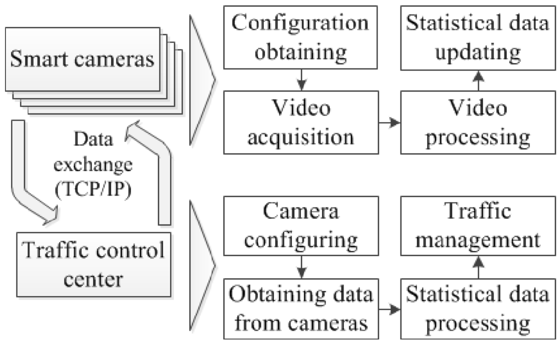

Figure 1. Vehicle detection and counting system.

Embedded online video processing reduces the amount of data transmitted to the traffic control center. Consequently, the requirements to communication channels and a computing server are reduced. However, we must remember that computing capabilities of such cameras are limited and image processing requires computational resources to account for many factors:

- Changes in scene illumination caused by shadows from clouds, trees, buildings.
- Moving shadows and glare caused by different positions of the sun.
- Light from vehicle headlights, glare on the road surface from streetlights.
- Weather conditions (rain, snow, fog).
- Various shooting angles of different cameras.
- A different configuration of observed road intersections and road sections.

II. Related Work

Current researches focus on improving methods of object detection on a basis of their movement. Such methods have the wide application in video analytics systems. There are two key areas of research.

The work has been supported by scholarship of the President of the Russian Federation for young scientists and postgraduate students (SP-2578.2018.5)

978-1-5386-5683-9/18/$31.00 ©2018 IEEE

First, researches are related to the improvement of optical flow estimation methods in terms of estimation accuracy and the amount of necessary computations [2, 3].

The second area is the development and improvement of background modeling methods [4-7]. In this area of research a significant number of works are devoted to the modification of statistical models of background brightness distribution. Attention is also paid to approaches for estimating the change in parameters of these models over time. In recent years some researches are related to background modeling by decomposition into matrices [8] and background modeling by decomposition into tensors [9].

There is a wide application of machine learning methods. Various mathematical approaches are used: neural networks, decision trees, cascade classifiers, and others [10-13]. The variety of existing mathematical methods of machine learning, the possibility of combining various mathematical models and the introduction of additional heuristic procedures lead to an appearance of new results in this field of research. At the moment it is difficult to distinguish one or more works that are better than others. The developed algorithms are still not universal and the quality of their work depends strongly on the completeness of a training set and its correspondence to typical operating conditions.

It should be noted that existing industrial solutions in the field of moving object detection and counting do not have sufficient efficiency. Academic studies are focused mainly on the development of theoretical approaches and it is often impossible to assess their performance in the entire range of real conditions. In addition, academic studies often do not pay enough attention to the computational complexity of algorithms. As a result, many proposed approaches are computationally complex for further practical implementation without the use of special hardware.

III. Vehicle Detection and Counting Algorithm

One of the promising tasks is estimating traffic density on highways, road intersections and streets of a city in order to increase efficiency of transport system management. The road traffic analysis systems can be used both for solving problems in real time (for an adaptive traffic control) and for obtaining of traffic flow statistics. Processing and analysis of statistical information allows us to propose effective measures to increase passenger and cargo traffic and traffic safety, for example, installation of traffic lights and regulation of their work, modification of a road intersection, building additional lanes (for common use and for public transport) and others.

The developed vehicle detection and counting algorithm requires the definition of special regions of interest (the sensors) in the image. The sensor is installed on each road lane (example is presented in the section "Experimental results"). Each sensor is divided into two zones (usually the entry zone and exit zone). This allows us to determine the movement direction of a passing vehicle, as well as perform a rough estimation of it speed if the distance between the zones has been specified.

The vehicle counter is incremented by one if the sensor detects the following sequence of events:

- The object is detected in the entry zone.
- The object is detected in the exit zone.
- The object has left the entry zone.

The initialization stage of the algorithm consists in the background modeling in each zone. At this stage the algorithm determines frames without motion. For this purpose the number of moving points on each frame is estimated:

- Calculating the difference between the current frame and previous frame.
- Obtaining the number of moving points by thresholding.
- If the number of moving points is greater than the threshold, depending on the resolution of the image, then it is considered that motion is detected in the zone. Otherwise, there is no motion.

The zones are synchronized to determine the moment when a vehicle left the entry zone and then left the exit zone. This step is necessary to exclude the selection of a reference frame at the time when a vehicle stopped in the zone. If there is no motion in the zone within the specified short time interval, then a reference frame is selected for background estimation.

After the reference frame selection, the stability of the background is checked for a predetermined time interval (usually several seconds). The difference between the reference frame and the current frame is analyzed for this purpose.

After the stage of the background estimation is completed, the zone goes into the normal operation mode, which contains the following steps:

- Calculating the difference between the current frame F and background frame B:

$$d_{x,y} = \begin{cases} F_{x,y} - B_{x,y}, & \text{if } F_{x,y} \geq B_{x,y}, \\ B_{x,y} - F_{x,y}, & \text{otherwise,} \end{cases} \quad (1)$$

where x, y – coordinates of the pixel.

- Thresholding to determine a number of points belonging to different categories: object, background, shadow, excessive lighting.

$$b_{x,y} = \begin{cases} 1, & \text{if } d_{x,y} > t_{bin}, \\ 0, & \text{otherwise,} \end{cases} \quad (2)$$

$$l_{x,y} = \begin{cases} 1, & \text{if } F_{x,y} \geq B_{x,y} \;\&\; b_{x,y} \equiv 1 \;\&\; F_{x,y} > t_{light}, \\ 0, & \text{otherwise,} \end{cases} \quad (3)$$

$$s_{x,y} = \begin{cases} 1, & \text{if } F_{x,y} < B_{x,y} \;\&\; b_{x,y} \equiv 1 \;\&\; F_{x,y} < t_{shadow}, \\ 0, & \text{otherwise,} \end{cases} \quad (4)$$

where $b_{x,y}$ indicates that the pixel does not belong to the background; $l_{x,y}$ indicates the presence of excessive lighting; $s_{x,y}$ indicates the presence of shadow.

The specific thresholds are defined to determine points belonging to the shadow (t_{shadow}) or excessive lighting (t_{light}). Filtering such points is necessary to avoid false detections. If a sufficiently large area of the zone is occupied by points related to an object, then the zone goes into the "vehicle detected" state. The final decision about vehicle detection is being taken at the sensor level, as described above.

IV. Road Marking Detection Algorithm

The vehicle detection and counting algorithm requires preliminary definition of regions of interest for each road lane. In order to automate this process it is proposed to perform a road marking detection for observed section of the road.

One effective method for detecting straight lines in an image is the integral vector Radon transform (IVRT) [14] which is defined as:

$$T(s,\alpha) = \int_{\sigma=s_{\min}}^{s} S(\sigma,\alpha)\,d\sigma,\ s \in [s_{\min}, s_{\max}], \tag{5}$$

where $S(\sigma,\alpha)$ – VRT result; (s,α) – line parameters.

However, its application to solve the described problem is limited by following factors:

- The IVRT is able to detect only straight lines along which marking lines lie but not end points of their segments.
- The IVRT is not able to detect curved marking lines.
- The distortion of some video cameras can significantly transform the originally straight marking lines.

In order to overcome these limitations, it is proposed to divide the source image into small fragments (blocks). We neglect line curvature and the inaccuracy in the determination of end points of segments within these blocks.

Lines detected by the IVRT in each block must be combined into long curved or straight lines that are taken as road marking lines. The multi-agent approach is used to solve this problem [15]. Each detected segment is associated with an active agent that seeks to connect with other neighboring agents [16]. A stable demand-resource network (DR-network) is formed as a result of several iterations of agent interaction. The network structure contains detected lines.

V. Experimental Results

The experimental researches of the developed algorithms and software were carried out using recorded real videos and on an embedded platform of smart cameras during the observation of different road sections in real time.

Video observation was carried out under different weather conditions and at different times of the day. The size of processed images is 1024 × 768 pixels.

A. Results for Road Marking Detection Algorithm

The use of the road marking detection algorithm is necessary to configure the operation parameters of the vehicle detection and counting system. In other words, results of this algorithm are required for the traffic control center operator (Fig. 1). Therefore experimental researches were carried out on a PC with the Intel(R) Core (TM) i7-3770 processor, 3.40GHz. We used images taken from 11 videos. The content of images differs both in a place and conditions of observation. Fig. 2 presents examples of a road marking detection.

Figure 2. Examples of road marking detection.

The results of experimental researches for different images are shown in Table I. Thus, the average efficiency of a road marking detection is about 76%.

TABLE I. Results of Road Marking Detection

Test image	Results	
	Number of correct detections	*Number of missing lines*
1	3	2
2	5	0
3	6	2
4	5	1
5	6	0
6	5	2
7	4	0
8	5	1
9	7	5
10	4	2
11	4	2

B. Results for Vehicle Detection and Counting Algorithm

The final implementation of the developed vehicle detection and counting algorithm is oriented to work on an embedded platform of smart cameras. The algorithm was tested on the network camera AXIS M2026-LE Mk II with Ambarella's ARM-based processor. The processing time for one frame was 4 ms when observing five lanes of the road.

Fig. 3 presents examples of vehicle detection and counting algorithm: images were obtained from different cameras when observing sections of roads with 3 and 4 lanes.

Figure 3. Examples of vehicle detection.

The results of experimental researches of the vehicle detection and counting algorithm for video sequences obtained under different observation conditions are shown in Table II.

TABLE II. RESULTS OF VEHICLE DETECTION

Test sequence	Results		
	Vehicle count	***Detection accuracy***	***False alarm rate***
1	657	99.69%	0.61%
2	505	99.29%	0.59%
3	458	100%	0.73%
4	1262	98.52%	0.65%
5	330	96.96%	1.35%

VI. CONCLUSION

In this paper we described the actual problems of the road situation analysis. The algorithms for processing video sequences obtained by an optical sensor when observing road sections were presented. These algorithms perform a road marking detection, vehicle detection and counting, evaluate parameters of traffic flows. The proposed algorithm for vehicle detection is also implemented and tested on an embedded platform of smart cameras.

The efficiency of the algorithms and developed software has been experimentally confirmed. After the analysis of the results, we can conclude that the developed algorithms allow to solve the considered problem in real-time under different observation conditions.

REFERENCES

[1] B.A. Alpatov, M.D. Ershov, “Real-time stopped vehicle detection based on smart camera,” Proceedings of 6th Mediterranean Conference on Embedded Computing (MECO), 2017, pp. 171-174.

[2] S. Aslani, H. Mahdavi-Nasab, “Optical flow based moving object detection and tracking for traffic surveillance,” International Journal of Electrical, Electronics, Communication, Energy Science and Engineering, vol. 7, 2013, pp. 789-793.

[3] C.S. Royden, M.A. Holloway, “Detecting moving objects in an optic flow field using direction- and speed-tuned operators,” Vision Research, vol. 98, 2014, pp. 14-25.

[4] D. Li, B. Liang, W. Zhang, “Real-time moving vehicle detection, tracking, and counting system implemented with OpenCV,” Information Science and Technology, 2014, pp. 631-634.

[5] G. Lee, R. Mallipeddi, G.-J. Jang, M. Lee, “A genetic algorithm-based moving object detection for real-time traffic surveillance,” IEEE Signal Processing Letters, vol. 22, 2015, pp. 1619-1622.

[6] N. Seenouvong, U. Watchareeruetai, C. Nuthong, K. Khongsomboon, N. Ohnishi, “A computer vision based vehicle detection and counting system,” Knowledge and Smart Technology, 2016, pp. 224-227.

[7] Z. Moutakki, I.M. Oulou, K. Afde, A. Amghar, “Real-time video surveillance system for traffic management with background subtraction using codebook model and occlusion handling,” Transport and Telecommunication Journal, vol. 18, 2017, pp. 297-306.

[8] T. Bouwmans, A. Sobral, S. Javed, S.K. Jung, E.-H. Zahzah, “Decomposition into low-rank plus additive matrices for background/foreground separation: a review for a comparative evaluation with a large-scale dataset,” Computer Science Review, vol. 23, 2017, pp. 1-71.

[9] A. Sobral, “Robust low-rank and sparse decomposition for moving object detection: from matrices to tensors,” PhD Thesis, 2017.

[10] H. Qin, Z. Zhen, K. Ma, “Moving object detection based on optical flow and neural network fusion,” International Journal of Intelligent Computing and Cybernetics, vol. 9, 2016, pp. 325-335.

[11] D. Biswas, H. Su, C. Wang, J. Blankenship, A. Stevanovic, “An automatic car counting system using OverFeat framework,” Sensors, vol. 17, 2017, pp. 1-13.

[12] K. Sundbeck, “Car detection with and without motion features,” Master’s Thesis, 2016.

[13] S. Choudhury, S.P. Chattopadhyay, T.K. Hazra, “Vehicle detection and counting using Haar feature-based classifier,” Industrial Automation and Electromechanical Engineering Conference, 2017, pp. 106-109.

[14] P. Babayan, N. Shubin, “Line detection in a noisy environment with weighted Radon transform,” Image Processing: Machine Vision Applications VII, 2014, pp. 1-6.

[15] V.A. Vittikh, P.O. Skobelev, “The multi-agent models of interaction in demand-resource networks,” Automatica and Telemechanica, 2003, pp. 177-185.

[16] P. Babayan, N. Shubin, “Detection of curved lines and estimation of their parameters on images,” Proceedings of 6th Mediterranean Conference on Embedded Computing (MECO), 2017, pp. 201-204.