Vehicle Detection and Tracking at Night in Video Surveillance

http://dx.doi.org/10.3991/ijoe.v9iS6.2828

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***Abstract*—This Many detection and tracking methods are able to detect and track vehicle motion reliably in the daytime. However, vehicle detection and tracking in video surveillance at night remain very important problems that the vehicle signatures have low contrast against the background. Traditional methods based on the analysis of the difference between successive frames and a background frame can not work. This paper presents a method for vehicle detection and tracking at night in video surveillance. The method uses Histograms of Oriented Gradients (HOG) features to extract features, and then uses Support Vector Machine (SVM) to recognize the object. In tracking phase, we use Kalman filter to track the object. As shown in experiments, the algorithm can exactly detect and track moving vehicles in video surveillance at night.**

***Index Terms*—Vehicle Detection; Tracking, Histograms of Oriented Gradients (HOG) features; Support Vector Machine (SVM); Kalman filter**

I. INTRODUCTION

With the rapid economic development, motor vehicles increase sharply in urban. In order to manage the traffic flow of our cities, we need to extract some information from the roads, information extraction is an increasing demand for applications such as traffic lights control, population evacuation, or to reduce traffic issues including congestion, pollution, and accidents. So the traffic video surveillance is increasingly important. Now a lot of researches have done for daytime vehicle surveillance at home and abroad, however traffic video surveillance should be normally and effectively worked in different environments, weathers and light conditions, so it is necessary to improve the performance of the traffic video surveillance at night to complete real-time monitoring. Due to the insufficient light intensity, poor contrast, most of the daytime vehicles' characteristic information is not available in the night. Vehicle detection and tracking with complicated illumination conditions have always been a difficult problem at night.

Many different approaches for vehicle detection and tracking have been proposed in the literature. R. Taktak. and al. [3] thought the headlights could be used as the most obvious characteristics of vehicles at night, extract the headlights as a car for vehicle detection. Separate the two headlights of a car according to the same relationship between the headlights to detect the traffic flow. OU Zhi-fang and al. [7] presented a methodology for night-time vehicle detection using D-S evidence theory. It paired the rear lamps using taillight clustering algorithm to get vehicles candidate hypothesis, using D-S evidence theory and fusing the feature information to find a belief threshold to set to verify the vehicle hypothesis. These papers [5][6][10] also used car light to detect objects. Kaiqi Huang and al. [13] presented an algorithm which is based on contrast analysis to detect moving objects in outside night surveillance.

In this paper we present a new method that consists of detection and tracking vehicles at night by using HOG features [1][4][9] and Kalman filter [14][15] techniques. Because of using proper algorithm, the method improves the detection and tracking performance and reduces the processing time.

II. VEHICLE DETECTION BASED ON HISTOGRAMS OF ORIENTED GRADIENTS (HOG) FEATURES

In vehicle detection phase, the key components are HOG features extraction and SVM classifier training. First, the input image is represented as HOG features which are later used as linear SVM classifier. Using the classifier perform a dense multi-scale scan reporting preliminary object decisions at each location of the test image. These preliminary decisions are fused to obtain the final vehicle detection. HOG features combined with SVM classifier have been widely used in image recognition, especially got a great success in object detection. Figure 1 shows algorithm flow of vehicle detection.

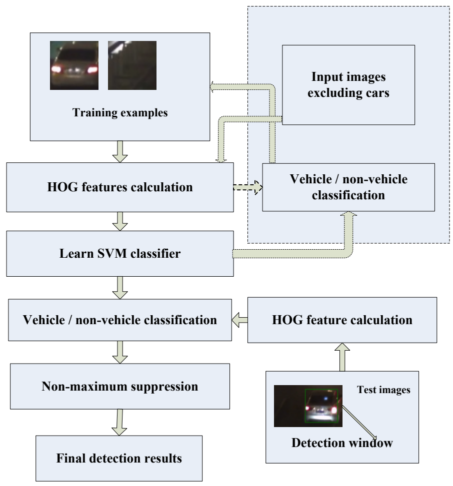


Figure 1. Algorithm flow of vehicle detection

A. Histograms of Oriented Gradients (HOG) features

HOG features are a kind of local descriptor, constitute the object characteristics by calculating gradient direction histogram the local area. In an image the gradient of the pixel of (x, y) can be denoted as:

$$G_x(x,y) = H(x+1,y) - H(x-1,y) \quad (1)$$

$$G_y(x,y) = H(x,y+1) - H(x,y-1) \quad (2)$$

Where $G_x(x,y)$, $G_y(x,y)$ and $H(x,y)$ indicate the horizontal direction gradient of input image pixel, the vertical direction gradient and the pixel values, respectively. The gradient magnitude and direction of (x, y) can be represented as:

$$G(x,y) = \sqrt{G_x(x,y)^2 + G_y(x,y)^2} \quad (3)$$

$$\alpha(x,y) = \tan^{-1}\left(\frac{G_y(x,y)}{G_x(x,y)}\right) \quad (4)$$

Navneet Dalal and Bill Triggs [1] presented the process of HOG features extraction, firstly, divide sample image into the cell of a number of pixels, equally divide the gradient direction into 9 bins, proceed histogram statistic for gradient direction of all pixels in each interval direction, and obtain a 9-dimensional feature vector. Every four adjacent units constitute a block, associate feature vector within a block to get 36-dimensional feature vector, and use block to scan the sample image. Finally, connect features of all blocks to get object features.

In the object detection, the main content of HOG features extraction for the following:

(1) The input color images is converted to grayscale;
(2) The Gamma correction method is adopted to color space standardization (normalized) of input image; the purpose is to adjust the contrast of image, reduce the shadow of local image and the impact of illumination changes. While it can restrain noise interference.
(3) Compute the gradient; mainly in order to capture the contour information and weaken the interference of light.
(4) Project gradient to the direction gradient of cell;
(5) All the cells are normalized in the block; normalization can further compress the light, shadow and edges, the block descriptor after normalization is called HOG descriptor.
(6) Collect HOG features of all the blocks in detection space; the purpose of this step is to collect HOG features for overlapping blocks in detection window, and combine them into the final feature vectors for classification.

We know vehicle detection and tracking under low illumination conditions is a difficult problem at night. HOG features are not sensitive to illumination change and can show better performance in characterizing object appearance and shape. So using HOG features is effective at night.

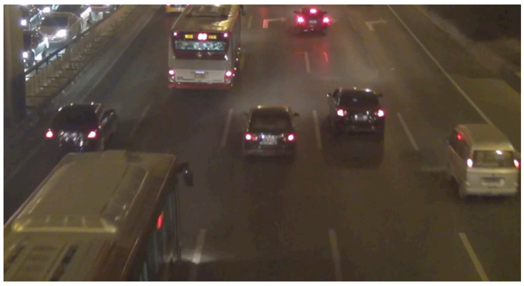


Figure 2. An example of nighttime traffic scene

$$W(k) = \sum_{i=j=0}^{8,8} \| G(x,y,k) \| \quad (5)$$

Where $G(x,y,k)$ indicates gradient intensity; k(1to9) indicates gradient direction. $W(k)$ is the sum of gradient amplitudes whose direction is k in each cell. When collecting HOG features of all the blocks in detection space, use the L2 normalized histogram to eliminate the influence of light in the block. The normalized histogram within all block consists of the last feature vector in detection window. Normalization method is given by the formula (6)

$$W_t^{'} = \frac{W(k)}{\sum_{(i,j)\in f(i,j)} G_t(i,j)} \quad (6)$$

Where $W_t^{'}(k)$ indicates the sum of gradient values in image block, $\sum_{(i,j)\in f(i,j)} G_t(i,j)$ indicates the sum of all gradient amplitudes in block (f(i,j)). Calculate $W_t^{'}(k)$ to extract features which can reduce the interference of light on the HOG features. By normalization method can effectively extract night target features.

B. Support Vector Machine (SVM)

The classification problem can be restricted to consideration of two-class problem without loss of generality. The goal is to separate the two classes by a function which is induced from available examples and produce a classifier that will work well on unseen examples.

Support Vector Machine (SVM) [2][9][11] is a kind of algorithm based on the principle of structural risk minimization, which has advantages in solving the small sample, nonlinear and high-dimensional pattern recognition problems. SVM is to find an optimal separating hyper plane which maximizes the distance between two classes to separate two classes with the largest interval.

In this paper, we take the method based on the SVM with HOG features to realize classification and recognition. We make manually 5829 positive samples and generate automatically 64060 negative samples by using image frames without vehicles. All the samples are scaled to the size of 64*64 (width×height) for training. Extract HOG features from all the training data, obtain high-dimension feature vectors and then train the linear SVM classifier using these vectors. Then scan the test images and find the possible areas including cars.

III. VEHICLE TRACKING BASED ON KALMAN FILTER

Kalman filter was proposed by Rudolf Emil Kalman who is a mathematician of United States in 1960. Kalman filter is the best linear filter in the minimum mean square error, which means that it makes mean square error which between the system state vector and the predictive value of state vector be minimum. The thought of Kalman filtering algorithm is continuously iterative update by forecast and update time sequence, making the error which is caused by system noise and observation noise gradually reduced, to get the best state parameters.

The Kalman filter uses the state-space model that includes the state equation and observation equation to describe the filter. According to the criteria of linear unbiased minimum mean square error estimation, the best estimate give the state variable by using the recursive nature of state equations and a set of recursive algorithm. The Kalman filter model is as follows:

$$S_k = \Phi_{k,k-1} \bullet S_{k-1} + \Gamma_{k,k-1} W_{k-1} \quad (7)$$

$$Z_k = H_k \bullet S_k + V_k \quad (8)$$

Where S_k is the n-dimensional state vector, $\Phi_{k,k-1}(n)$ is the n×n-dimensional state transition matrix, $\Gamma_{k,k-1}$ is the n×p-dimensional noise input matrix, W_{k-1} is the p-dimensional system process noise, Z_k is the m-dimensional observation sequence, H_k is the m×n-dimensional observation matrix, V_k is the m-dimensional observation noise sequence.

The core of Kalman filter is the evaluation model which is also one of recursive algorithms, the state estimates and the current observed values determine the state estimation value. It is problem of Kalman filter that the linear minimun variance estimation $\hat{S}_{j,n}$ of the state S_j is calculated based on observed value $(Z_n, Z_{n-1}, \ldots Z_1)$. The minimun target is as follows:

$$J = E\left[\left(S_j - \hat{S}_{j,n}\right)^T \left(S_j - \hat{S}_{j,n}\right)\right] \quad (9)$$

When j = t the formula (7) is Kalman filter, when j<t the formula is smoother, when j>t the formula is predictor.

The important equation of Kalman filter is as follows:

$$\begin{cases} \hat{S}_{k,k-1} = \Phi_{k,k-1} \hat{S}_{k-1} \\ \hat{S}_k = \hat{S}_{k,k-1} + K_k \left[Z_k - H_k \hat{S}_{k,k-1}\right] \\ K_k = P_{k,k-1} H_k^T \left[H_k P_{k,k-1} H_k^T + R_k\right]^{-1} \\ P_{k,k-1} = \Phi_{k,k-1} \xi_{k-1} \Phi_{k,k-1} + \Gamma_{k,k-1} Q_{k-1} \Gamma_{k,k-1} \\ \xi_k = \left[I - K_k H_k\right] P_{k,k-1} \end{cases} \quad (10)$$

The formula 10 describes the observation update process of Kalman filter, from the priori estimates ($\hat{S}_{k,k-1}$) and the prediction error covariance matrix P(n). The first equation of formula 10 is the method that the k state is estimated by the k-1 state, the second equation update estimation ($\hat{S}_k$) of the state vector (S_k), the third equation calculates the optimal gain factor (K_k), then the new observation vector (Z_k) will calculate the updated parts ($K_k\left[Z_k - H_k \hat{S}_{k,k-1}\right]$), As for the quality of forecasts, the fourth equation makes a quantitative description. The other equations are used to calculate the rectification value of time-updated, the rectification value reduce from the quality of time update ($P_{k,k-1}$), the quality of observing information (R_k), the relationship between observation and the state (H_k) and the specific observation information (Z_k). The purpose of all equations is to ensure that observation information is correct and rational used.

According to the principles of Kalman filter, we can predict the position of the object in the next frame. In this way, we improve the accuracy of tracking and decrease the rate of the object undetected.

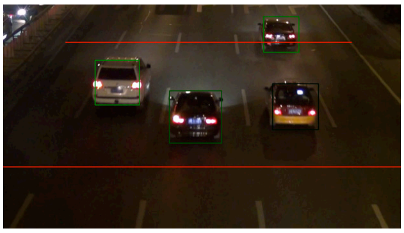
IV. EXPERIMENTAL RESULTS

The proposed approach is evaluated on a group of test captured from video stream shot downtown. We select 5829 positive samples and 64060 negative samples. Figure 3 shows our positive samples; Figure 4 shows our negative samples.

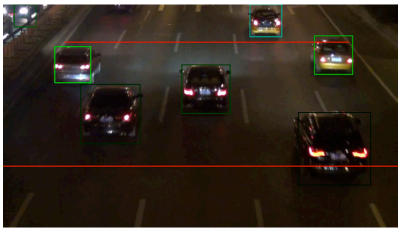
Figure 5 shows the results of our algorithm. The light condition is very poor. From Figure 5(b) and Figure 5(c), we can see that the accurate detection rate is also high when traffic volume is large and the video is fuzzy. Figure 6 shows the results of the detection and tracking. Color boxes are the detection boxes, white boxes are the tracking boxes. The number on the upper-left corner shows the amount of passed cars, traffic flow is very important for the intelligent transportation system.

Figure 3. Positive samples

Figure 4. Negative samples



(a) The number of cars less



(b) The number of cars more

(c) Video is fuzzy

Figure 5. The result of vehicle detection at night

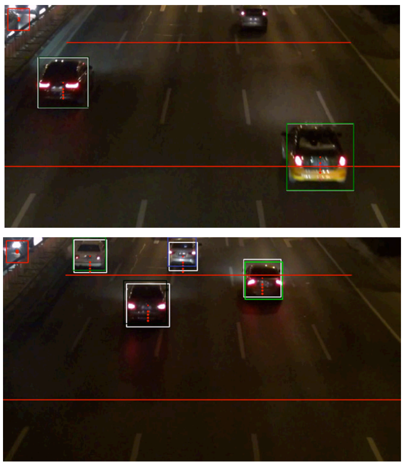


Figure 6. The result of vehicle detection and tracking at night

TABLE I.
THE RESULT OF VEHICLE DETECTION OF DIFFERENT VIDEOS

Test video	Detection vehicles	Actual vehicles	leak detection	more than the actual detection
Video 1	61	62	1	0
Video 2	204	211	7	0
Total No. car	265	273	8	0
Time span of video	10.14 minutes			
Detection rate	97.07%			

TABLE II.
COMPARISON OF DETECTION RESULTS BETWEEN OUR SYSTEM AND OTHER METHODS

Methods / Detection rate	Frame difference	D-S evidence theory	HLEPT algorithm	Vision and sonar sensor fusion	Our algorithm
Detection rate	96.48 %	95.38%	96.4%	85%	97.07 %

As shown in table 1, we can know the algorithm speed is high. It has good detection and tracking effect for quickly moving targets like vehicles. It can randomly detect and track vehicles which come into the monitoring scenario. The detection rate is 97.07%.

The comparisons of the detection rate between our algorithm and other methods are shown in Table 2. Error detection rate of vehicle detection at night based on frame difference [17] would rise when the traffic flow is larger. The D-S evidence theory [7] has the problem when vehicles steer at night, due to the influence of the rear turn signal, the bright block segmentation may appear error in image preprocessing. The HLEPT algorithm [18] is vulnerable to a variety of lights and the reflection of the lights. The vision and sonar sensor fusion method [16] is required the faithful distance estimation method using a single camera which can access the danger of collision. Our algorithm not only overcomes the shortcoming of insufficient light, but also is less affected by speed of a motor vehicle, curve and all kinds of illuminant.

V. CONCLUSION

In this paper, we propose a method for vehicle detection and tracking at night in video surveillance. Our system makes use of HOG features to extract vehicle features and SVM to realize classification and recognition. Then uses Kalman filter to track vehicles. The method effectively overcomes the shortcoming of insufficient light at night. Experimental results show that the system is effective and accurate, the system can achieve high vehicle detection rate at night.

ACKNOWLEDGMENT

This work is supported by Project of Beijing Municipal Commission of Education (No.KM201210009008) and Natural Science Foundation of China (No. 61103113).

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This work is supported by Project of Beijing Municipal Commission of Education (No.KM201210009008) and Natural Science Foundation of China (No. 61103113). It is an extended and modified version of a paper presented at the 2012 International Conference on Artificial Intelligence and Its Application in Industry Production (AIAIP 2012), held in Wuhan, China in December 2012. Manuscript received 19 May 2013. Published as resubmitted by the authors 26 June 2013.