Video Vehicle Detection Algorithm Based on Virtual-Line Group

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***Abstract*—The paper presents the video vehicle detection algorithm based on virtual-line group. The algorithm uses virtual-line group to optimize the states of detection lines in both spatial domain and temporal domain by setting the domain-knowledge based rules. By synthesizing the optimization information in the larger spatio-temporal scale, the algorithm can improve the precision of vehicle detection. The experiment results and the detailed analysis demonstrate that the algorithm is real-time, accurate and robust.**

***Keywords*—virtual-line group, video vehicle detection, spatial, temporal**

I. INTRODUCTION

With the rapid development of traffic, more and more modern technologies are engaged in the utility of traffic supervision and control [1]. One of the most widely used methods is the video vehicle detection (VVD). This method can both get abundant real-time data and pictures and implement the scene feedback and control using Ethernet communication, 485 communication or wireless communication and so on [2]. VVD has advantages of better real-time performance, higher accuracy and easier maintenance [3].

With the technology of image processing, VVD system can provide many vehicle parameters [4]，such as vehicle flux, instantaneous speed, average speed, vehicle density, vehicle classification. However, the accurate judgment of vehicle presence is the precondition of obtaining these parameters. Therefore advanced VVD algorithm is very essential in the process of vehicle detection.

In the research field, the vehicle detection algorithm generally can be classified into three kinds, namely, background subtraction method, inter-frame subtraction method and probability-based method.

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The virtual-line-based algorithm is an important solution in background subtraction method. Because this algorithm has the advantages of high operation speed and strong real-time ability, it is widely implemented in reality [5]. To avoid the disadvantages of low self-adaptive ability and inferior robustness of this algorithm, the inter-frame subtraction method is proposed. Inter-frame subtraction method computes difference between two successive frames so as to remove static part and get moving part within the image [6]. The merit of the algorithm is strong robustness to environmental change, but it is unable to detect static vehicle and makes some detection errors when the speed is too low and too high. To make the detection more perfect, probability-based method is presented by Paragios and Deriche in [7]. The paper considered a probability and statistics problem, and used the observed information to obtain a classification equation of probability to segment image. The algorithm has good performance in detection and track, but it suffers from the high computing cost and is not available in real-time monitoring system.

To avoid disadvantages mentioned above, the paper presents a novel VVD algorithm based on the virtual-line group (VLG). This algorithm uses luminance values of each pixel and spatio-temporal optimizing approach to detect vehicle. Additionally, it efficiently restrains the influences of shadows, window reflection, tailgating vehicles, special vehicles, etc, on the accuracy of detection.

The rest of the paper is organized as follows: Section II specifically illustrates the VVD algorithm based on VLG. Firstly, the detection principle based on the single virtual line is briefly explained, which is the elementary principle for VLG based method. After getting the origin state of each detection line, VLG, namely, the states of adjacent detection lines, is set in both spatial domain and temporal domain and processed to optimize the states of the detection lines. In the end, the final judgment is made by synthesizing spatio-temporal optimizing information. Section III presents the experiment results, including accuracy analysis and real-time ability analysis. The experiment is performed on the hardware using VLG-based algorithm and virtual-line based algorithm. Section IV shows the conclusion and future work.

II. VVD ALGORITHM BASED ON VLG

A. *Detection Principle Based on the Single Virtual Line*

Virtual line is in fact a pixel strip in one frame. One horizontal virtual line (VL) and one vertical virtual line are shown in Fig.1. Vehicles can be detected by analyzing the difference of the luminance values in the virtual line between the current frame and the background. The algorithm procedure is illustrated as following:

1) Initializing background value and setting threshold R_{th}. The detailed method is presented in [8].

2) Calculating the luminance value difference between the current frame and the background.

The background estimate is subtracted from the current image data [9] according to

$$R = \sum_{i=1}^{L} |(Pi - Bi)| / L \qquad (1)$$

where *Pi* and *Bi* respectively denote the *i*th corresponding pixel on the virtual line in the current frame and the background and L indicates the total point number of a virtual line. The spatial averaging method is used in Eq. (1).

3) Binary decision

After background differencing, the feature value R of the frame is generated. R is used to be compared with the threshold R_{th}.

a) If R> R_{th}, the detection line state is 1, which means that there are vehicles passing the detection line.

b) If R<= R_{th}, the detection line state is 0, which means that there are not vehicles passing the detection line.

B. *Setting VLG*

The vehicle detector is comprised of VLG. The group consists of four virtual lines, namely, detection line (deteline). The number of pixels and the setting of virtual lines depend on the different situations. In the VLG-based algorithm, there are two kinds of VLG. One is spatial VLG shown in Fig.2. Four adjacent horizontal virtual lines are selected in one frame. The VLG is four-unit length in Y dimension and has the same length with the frame in X dimension. The other is temporal VLG shown in Fig.3. Four horizontal virtual lines which are at the same position in each frame are chosen in four consecutive frames. The VLG is four–unit length in T dimension and has the same length with the frame in X dimension.

C. *Spatial Optimization of VLG*

In the spatial domain, it is supposed that the interval between two vehicles is hardly less than the interval represented by three lines.

Depending on the principle of camera setting, the interval represented by one line is definitely between 40mm and 200mm. Thus the interval represented by 3 lines is less than 1m. It is prescribed in the 80th byelaw of Law of the People's Republic of China on Road Traffic Safety that on the freeway the interval of two adjacent vehicles with the speed above 100km/h should be more than 100m, the interval of two adjacent vehicles with the speed below 100km/h should not be less than 50m and in the crowded urban road the interval is permitted to be less than 50m but should be more than 1m for safety. Therefore, the supposition above is reasonable.

From the detector in Fig.2, deteline1,2,3 and deteline2,3,4 which are consecutive virtual lines respectively constitute two detection groups. To deteline1,2,3, there are 8 possible states:

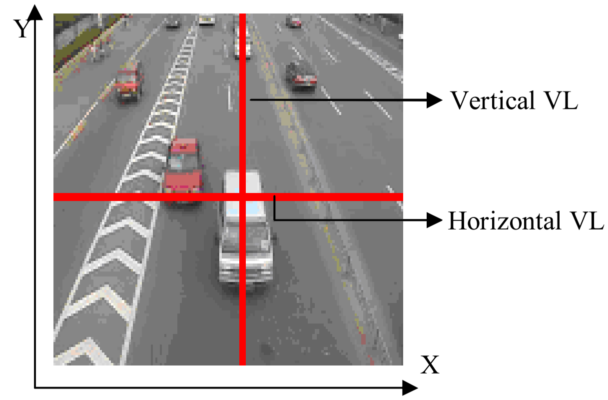

Figure 1. Virtual line

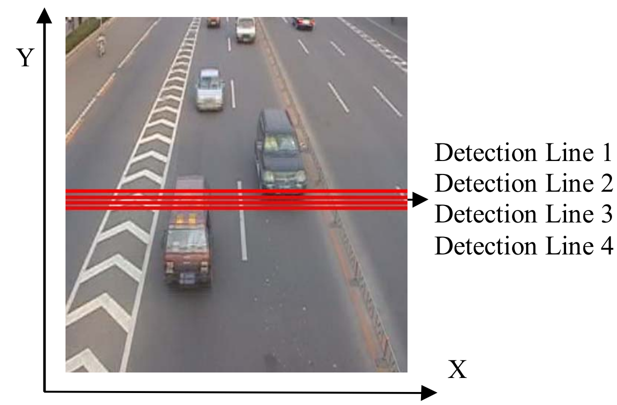

Figure 2. Spatial VLG

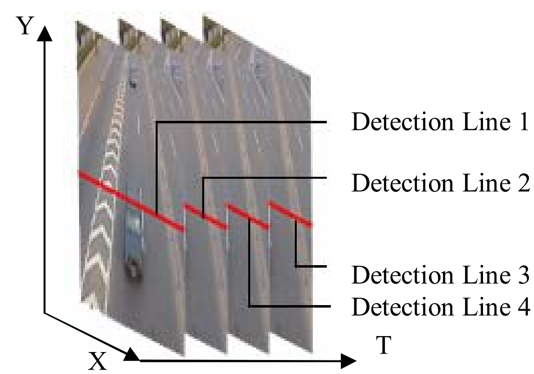

Figure 3. Temporal VLG

$$(0,0,0),(0,0,1),(0,1,0),(0,1,1)$$

$$(1,0,0),(1,0,1),(1,1,0),(1,1,1)$$

There are two false states, (1,0,1) and (0,1,0).

Depending on the supposition above, two adjacent vehicles can not be so close to each other like that. As a result, these two states are definitely false. The state, (1,0,1), is modified as (1,1,1) and the other state, (0,1,0), is modified as (0,0,0). Thus the real states of deteline2 are optimized. Besides, the real state of deteline3 can be optimized in the same way. Then the states of deteline2 and deteline3 can be used to detect vehicles.

D. Temporal Optimization of VLG

In the temporal domain, it is supposed that a vehicle is impossible to get across any virtual line within one frame interval. Besides, the temporal interval between two vehicles is more than one frame.

In PAL standard, frame rate is 25f/s. On one hand, to a vehicle the speed of which is about 180km/h, it can advance about 2m within one frame interval. Universally, the length of one vehicle is more than 3m. Therefore, the same vehicle can be detected more than once on one virtual line. On the other hand, if the temporal interval of two vehicles is only one frame, the interval in space between two vehicles with the speed about 180km/h is about 2m and to two vehicles with the speed about 90km/h the interval between them is merely 1m. These results disobey the 80th byelaw of Law of the People's Republic of China on Road Traffic Safety. As a result, the supposition above is reasonable.

In the temporal domain, consecutive 3 frame states which are represented by state[1], state[2] and state[3] are regarded as one group for each detection. To the three frames, there are 8 possible states:

$$(0,0,0),(0,0,1),(0,1,0),(0,1,1)$$

$$(1,0,0),(1,0,1),(1,1,0),(1,1,1)$$

There are two false states, (1,0,1) and (0,1,0).

The state, (1,0,1), is modified as (1,1,1) and the other state, (0,1,0), is modified as (0,0,0). Thus the real states of virtual lines in each frame are optimized.

E. Final judgment by Synthesizing Spatio-temporal Optimizing Information

After the states of four virtual lines in VLG are optimized using spatio-temporal information, there are three kinds of results as following:

1) If the state of each line fulfills the spatio-temporal requirements, the states of deteline2, 3 are used to detect vehicles.

2) If one requirement is not fulfilled, either spatial or temporal one, VLG is optimized using the corresponding method and then the result is analyzed. This process is done with the recursive method until both the spatial and temporal requirement are fulfilled.

3) If neither requirement is fulfilled, the spatial optimization method is firstly used because the adjacent virtual lines in space have greater continuity than the same line in consecutive frames in time. Then VLG is optimized in the way as is mentioned in *2).*

If there comes the recurrence in the same state, timeout is set and the optimal result is regarded as the final result.

After optimizing the states of virtual lines with spatio-temporal information, the states of deteline2 and deteline3 are used to make the final judgment as following:

1) If the states of deteline2 and deteline3 are all 1, there are vehicles passing VLG.

2) If the states of deteline2 and deteline3 are all 0, there are no vehicles passing VLG.

3) If the state of one line is 1 and the state of the other is 0, the result is determined with Table I depending on the states of the former and latter frames in the temporal domain. The reasons mentioned above are explained as following:

a. It is not very probable to be detected by the second line directly without being detected by the first line before.
b. It is impossible that a vehicle do not move within the time of the two consecutive frames.
c. It is reasonable in logic.
d. It is impossible that two vehicles are so close to each other.

TABLE I. DETECTION REFERENCE

Current Frame	Former frame	Latter frame	Vehicle	Reason
01	00	X	NO	a
	01	X	NO	b
	10	00	YES	c
	11	00	YES	c
10	00	01，11	YES	c
	01	X	NO	d
	10	X	NO	b
	11	X	NO	d

III. EXPERIMENT RESULTS

A. Accuracy Analysis: Comparison between Two Algorithms

Usually, the quantitative evaluation of a retrieval system is performed through the Precision-Recall Curve.

Precision-Recall Curve:

Precision for a query q[Pr(q)] is defined as the ratio of the number of retrieved relevant objects, say, N(q) over the number of total retrieved images, say, M. On the other hand, recall of a query q[Re(q)] is the ratio of the number of retrieved relevant objects N(q) over the total number of relevant objects in the database for the respective query, G(p)。

$$Pr(q)=N(q)/M,Re(q)=N(q)/G(q) \qquad (2)$$

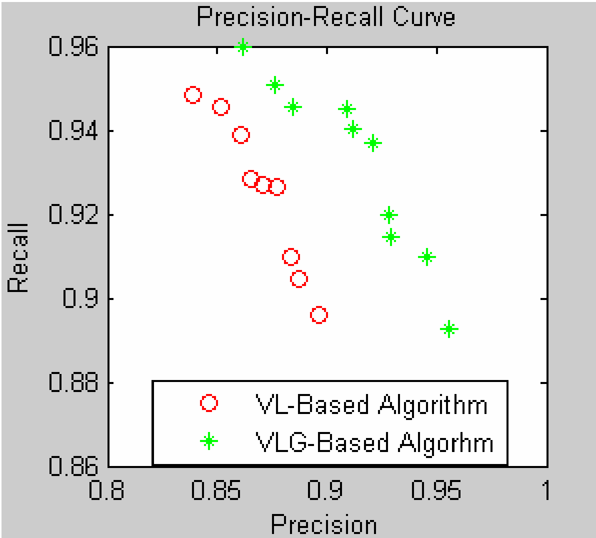

Figure 4. Precision-Recall Curve

In a real retrieval system, as the number of objects returned to the user increases, precision decreases, while recall increases. Because of this, instead of using a single value of Pr(q) or Re(Q) , the precision-recall curve is usually adopted.

In the experiment ten different pieces of video are put forward to be tested respectively using virtual-line-based (VL-based) algorithm and VLG-based algorithm. The videos are shot above the freeway at about 3:00 pm and each one lasts for 8 minutes. Fig.4 shows us the Precision-Recall Curve. The experiment result strongly demonstrates VLG-based algorithm has higher precision and recall by using spatio-temporal optimizing approach than VL-based algorithm. Therefore VLG-based algorithm is a promising method with stronger robustness and higher precision.

B. *Real-time Ability Analysis*

The experiment is performed on the hardware based on the Texas Instruments 6211DSP chip. This chip is a high performance and highly integrated digital signal processor. It is used to fulfill the real-time requirement.

It is prescribed in PAL standard that the frame rate is 25f/s. Thus each frame has 40ms of time to be processed. Experiment results indicate that vehicular detection is executed within input acquisition interval. Moreover there is three-frame interval to transfer video and traffic data to PC. This can be hidden in pipelining. So real-time processing can be finished. Through the Profile tool of CCS IDE, the code of detection module can be performed within 12us. So the detection can be finished in real time.

IV. CONCLUSION AND FUTURE WORK

The experiment results demonstrate that the VVD algorithm based on VLG effectively increases the accuracy of vehicle detection using spatio-temporal optimizing approach. What is more, it fulfills the real-time requirement. Compared to the virtual-line based algorithm, this algorithm has greater precision and robustness together with similar operation complexity. Therefore, The VVD algorithm based on VLG is a feasible and promising algorithm.

Till now VLG-based algorithm only uses the horizontal VLG in Fig.2 and Fig.3 because setting the vertical VLG is more difficult. However, the vertical VLG will definitely help to increase the precision and recall. So setting the vertical VLG is a useful problem. Besides, detecting the presence of vehicle shadows is another essential problem to improve the detection algorithm. Therefore, it is valuable to keep on with the work mentioned above.

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