JST: Smart Systems and Devices
Volume 31, Issue 2, September 2021, 043-050

A Study on the Shutter Time of a Surveillance Camera to Improve Speed Detection Accuracy of Vehicles on Highways and Inner-City Streets

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Abstract

Detection of vehicle speed based on image processing technology recently has been found in many applications over the world. However, the accuracy of those methods has not been investigated taking into account of physical characteristics of the surveillance camera. Based on the operation time of the camera's optical sensor system including shutter time (ST) and sensor operating time, the accuracy of vehicle speed detection on highways as well as inner city streets can be significantly improved. The operation time of the camera's sensor is essential for determination of frames over time in a vehicle surveillance system. Therefore, control of the shutter time ST will help a camera-based speed detection system to achieve much better accuracy.

Keywords: Vehicle speed detection, surveillance camera, image and video processing, shutter time.

1. Introduction

An intelligent transportation system includes many functions for traffic management. A problem of vehicle speed detection utilized image processing technologies has been studied for a long time as basic studies [1] besides sensors-based solutions [2] as well as a combination between the two approaches. Traditionally, vehicle speed detection or surveillance is obtained using radar technology, particularly, radar detector and radar gun. However, this method still has several disadvantages such as the cosine error happening when the direction of the radar gun is not on the direct path of the incoming vehicle. From this study, it is known that vehicle detection is the main thing to understand on traffic condition reasoning, a starting point of understanding the traffic conditions based on the extraction of data from image processing. The improvement of image tracking will produce more accurate data for further implementation in traffic conditions through reasoning, such as accidents or broken cars. According to [3], the authors apply these methods on the virtual line based on various time-spatial images (TSIs) that are retrieved from multiple virtual detector (MVDL) lines of vehicle video frames. This method may be effective in implementing the autonomous system of transportation, but not well capable of handling the traffic complexity conditions, which is typical in Vietnam with a mixed flow of motorbikes and cars in inner city streets. On the other hand, Lin *et. al* [3] has been proposed some of the techniques in detecting various vehicles at the areas that cover with blind spot by unifying the edge-based method with an appearance-based method. However, the results are not achieving satisfaction since the background is quite complicated.

Video image processing-based speed detection focuses on two main directions. The first one utilizes a surveillance camera for speed detection [4,11,14] dealing only with the capture of a video stream and detection of vehicle speed without considering the operating time of the camera. The second direction instead uses two cameras [5], which typically are stereo or dual cameras to estimate the distance from a vehicle to the camera. Since the detected speed accuracy is strongly dependent on the moving speed of vehicles on highways and therefore on opening and closing ST of the cameras, this paper will deal with investigation of the influence of ST on the speed detection problem in a typical highway and mixed traffic system likely Vietnam. In [6] the authors already have studied geometrical modeling to provide a solution to detect vehicle speed in urban areas in Vietnam, where vehicles move at an average range of speed, but not applicable to ones moving at higher speeds. Therefore, this study may be utilized as a premise to expand widespread applications of modern image processing techniques in vehicle speed detection in highways as well as in inner city streets in Vietnam with a typical mixed traffic flow, where different means like cars, vans, buses, motorbikes, etc. both joining transportation.

To demonstrate the performance of the proposed method, the rest of this paper is organized as follows. Section 2 briefly introduces the system modelling of a

ISSN 2734-9373
https://doi.org/10.51316/jst.152.ssad.2021.31.2.6
Received: August 19, 2020; accepted: January 27, 2021

surveillance camera in traffic monitoring and the effect related ST considerations of the camera. Section 3 discusses the experimental results and performance evaluation. Finally, Section 4 deals with the conclusion and future works of this paper.

2. System Modelling

2.1. Geometric Model of a Camera

The essence of a camera is its lens system [7,13]. Fig. 1 demonstrates the position of an object according to the incident ray passing through O which is the center of the lens. The image obtained on the screen reflects the object thanks to the optical phenomena in the lens which is real and inverted to the object. The closer the object is to the viewfinder, the larger size it has. This viewfinder receives lighting source passing through a lens system of the camera, and then an image reflecting the object will be created on the screen at the focal length *f*. The pixel position of a reflected point from the object into the image plan can be evaluated from the object's coordinates in 3D space as in [5]:

$$i = f\frac{X}{Z} \text{ and } j = f\frac{Y}{Z} \tag{1}$$

where, X, Y, and Z are the pixel coordinates in the OXYZ space; f is the focal length of the camera lens system.

The camera location must be set up over the surface of the road with its optical axis inclined downward to the roadway to cover the road plane. Since the proposed solution focuses on speed detection of vehicles on both highways and inner city streets with a mixed traffic flow of motorcycles, cars, vans and other means, there is the need to identify each type of means out of each other in multiple road lanes. Therefore, this paper utilizes the direction angle (DA) of the first primary axis (FPA) for each coming vehicle detected in the video sequence and captured by the surveillance camera mounted on the roads [6]. The background subtraction is first performed for the captured frame sequence and then each vehicle is located and the DA of FPA is evaluated for decision making in identification task [8].

The study in [6] modelled the location of the surveillance camera installation on the road as shown in Fig. 1 below. Camera calibration is one of the important aspects of the study. The vehicles' location in video images is 2-D (dimension), however, the vehicles in real world are 3-D, but because vehicles cannot leave the road surface, vehicles' motion is also in 2-D which makes the transformation of image coordinates and vehicles' coordinates a 2D-to-2D mapping that can be precisely formulated. In this section, the calculation of the pattern function between vehicle coordinates in the image and real-world coordinates is performed. How the video camera is installed when the video images are captured from the road traffic and what characteristics are involved in that has to be determined. As shown in Fig. 1, the camera is set at the height of h above the road surface with its optical axis sloped at an angle δ from the road. The relation between camera lens angle and the view domain covered by camera can be determined using frequent geometrical equations. In short, the camera calibration parameters are set as follows:

1) Camera elevation angle range is α towards the vertical axis and $\alpha + \delta$ is the maximum adjustable elevation angle of this camera;

2) An obtained image I is at resolution is $m \times n$ pixels;

3) The camera is located at the height h evaluated from the road surface;

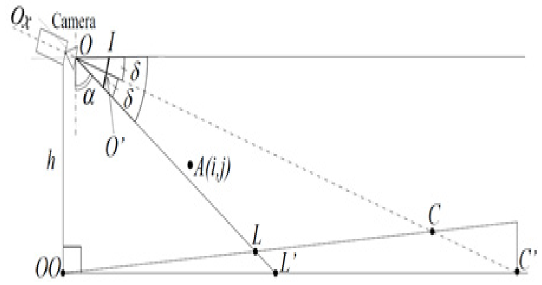


Fig. 1. A model of a surveillance camera calibration mounted on roads.

Assuming the camera's viewing angle along Ox-axis direction intersects the road surface at point C, which is always set up as a center of the captured image since point C corresponds to the center of the camera's image sensor. Point L is the closest position on the road where the camera can capture. Taking into account those parameters in this model setup, the distance from the camera to the object can be essentially evaluated.

If O' is assumed to be the center of the camera's image sensor, angle O'OA between O, O' and a given pixel *A(i,j)* on the image plan *I* of size $m \times n$ may be determined as:

$$OO'A = \tan\frac{\sqrt{\left|i-\frac{m}{2}\right|^2+\left|j-\frac{n}{2}\right|^2}}{f} \tag{2}$$

Utilizing the properties of circle, rectangles and trigonometry, all pixels in the image plan *I* will be determined corresponding the angle range scanned by the camera.

Since this problem focuses only on evaluation of vehicle speed, a vehicle is assumed to move in a straight direction, and therefore only the pixels along the horizontal frame boundary are the target under consideration to determine the movement distance of the vehicle followed by estimation of the vehicle speed. Let denote Δp the size of one pixel on the image sensor, its representation can be written as:

$$\Delta p = \frac{f.\tan(\delta)}{m/2} \tag{3}$$

From the known angles α and δ, the position of pixel *A(i,j)* on the resulting image I at the distance from the centre of OO' can be found as follows:

If pixel $A(i,j)$ **for** $i \geq \frac{m}{2}$ **then**:

$$d = h.\tan\left(\alpha + \left(\delta - \arctan\left(\frac{\left(i - m/2\right)\Delta p}{f}\right)\right)\right) \tag{4}$$

And **if** pixel $A(i,j)$ **for** $i < \frac{m}{2}$ **then**:

$$d = h.\tan\left(\alpha + \left(\delta + \arctan\left(\frac{i\Delta p}{f}\right)\right)\right) \tag{5}$$

2.2. Vehicle Identification

In this important step, the background subtraction method is investigated to find the difference between the images or sequence video frames, followed by identification of moving objects in the video frames afterward.

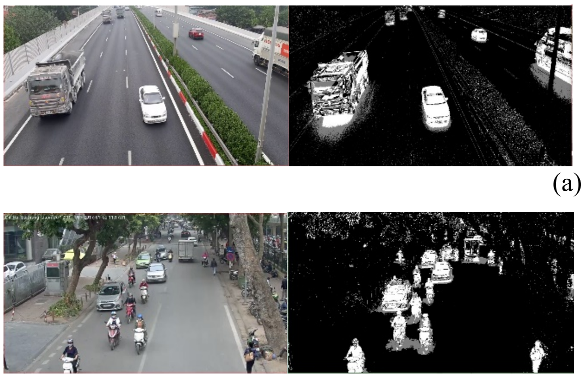
Background subtraction is a widely used approach for detecting moving objects in videos from static cameras [8,9,12]. The rationale in the approach is that of detecting the moving objects from the difference between the current frame and a reference frame, often called the background image or background model. As a basic, the background image must be a representation of the scene with no moving objects and must be kept regularly updated so as to adapt to the varying luminaries' conditions and geometry settings. Therefore, binarization should be the very first step in the background and foreground separation process, which are road surface and vehicles, respectively as illustrated in Fig. 2.

In [8,9], Stauffer and Grimson describe the probability as observation of a pixel x at time t within a given image I is the average of a multivariable mixed Gaussian model that represents color values of red, green and blue respectively as presented in formula 6. Herein it is assumed that these values are independent and have the same variance σ_K^2 :

$$P(x_t) = \sum_{i=1}^{K} \omega_{i,t}\eta(x_t - \mu_{i,t}, \sum_{i,t}) \tag{6}$$

Here, η denotes the probability density function, and K the number of Gaussian variables in each Gaussian distribution, and in fact, it is set to the value between 3 and 5. Each of these distributions describes only one of the objects belonging either to the foreground or background and then is sorted based on the weights $\omega_{i,t}$. The data herein that relate to the i_{th} Gaussian variable at time t in this combination and the covariance function $\sum_{i,t}$ of this Gauss variable has the form $\sigma_k^2 I$.

In order to improve the efficiency of vehicle identification through a surveillance camera system, this paper utilizes the proposed method in [10] combined with investigation of incidence angle of each incoming vehicle and mapped into the predefined database to identify the vehicles instead determination of the vehicle sizes. Based on identification results, the localization of the vehicles and their licence plates will be detected and bounded by boxes, and the corresponding centroids will be utilized in speed detection step on either highway with allowed vehicles or on inner city streets with any types of vehicles.



(a)

(b)

Fig. 2. A frame captured from surveillance camera and its background extraction. a) On a highway. b) On a street

2.3. A Video Frame

The surveillance camera operates at 12 frames per second (fps). A frame map example captured from the camera in this system is given in Fig. 3.

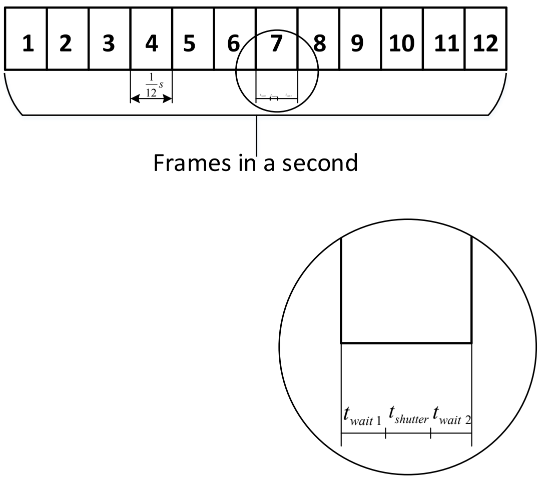


Fig.3. Representation example of a frame map captured from the surveillance camera operating at 12 fps.

The interval between two consecutive frames can be easily determined as 1/12 second. While a vehicle coming from a distance toward the surveillance camera, the vehicle displacement Δs in the time interval Δt is estimated by utilization of the consecutive frames captured within Δt. The actual average speed $\overline{v}$ of the vehicle is then determined from the following formula:

$$\overline{v} = \frac{\Delta S}{\Delta t} \qquad (7)$$

According to the method presented in [6], only the nearest pixels to the camera which belong to the vehicle region will be considered to estimate the centroid of the vehicle object. Fig. 4 demonstrates a frame extracted from a video sequence which is recorded on Phap Van – Cau Gie Expressway. Estimation of the displacement of the centroid for a time interval attached with the vehicle object appearing in the consequent frames will be utilized to approximate the vehicle speed.

2.4. *Shutter Opening and Closing Time*

This session deals with the investigation of the vehicle centroid to estimate the displacement of the vehicle from the localized license plate as well as vehicle's region of interest (ROI). In addition, the traffic density is also considered in this study to verify the proposed solution. As shown in Fig. 4, the centroid of the license plate and that of vehicle object detected are almost duplicated. Therefore, the centroid positions are useful to be served in the speed measurement process, where vehicle's centroid is suitable for highway and license-plate's centroid is effective for streets, especially with crowded traffic because vehicles are partially hidden in the traffic crowd and not easy to be fully extracted and then localized.

Fig. 5 shows the relationship between the centroid of the detected vehicle and bounded by a rectangular box and that of the localized license plate. Utilization of this data is helpful to investigate the vehicle-related information while it moves across the sensor quadrants as shown in Fig. 6. Of course, this matter is also partially dependent on the elevation angle of the mounted surveillance camera. If there is a mismatch of the centroid info observed in the sensor quadrants in Fig. 6, it means that the vehicle is approaching from afar toward the camera position. Whenever vehicles are viewed by the camera from a distance, the angled slope as described in [10] is investigated to classify vehicles in the very first captures if the rectangular box where the vehicle is surrounded by is detected horizontally. However, if a vehicle approaches from afar to a given distance, it may pass through the centre of the camera sensor system, and the detected box may be rotated from the horizontal to vertical view. In fact, each of these parameters can be investigated to detect vehicle speed in the traffic flow.

Fig. 4. An example of a frame extracted from the surveillance video sequence in database. a) Captured on a highway. b) Captured on a street

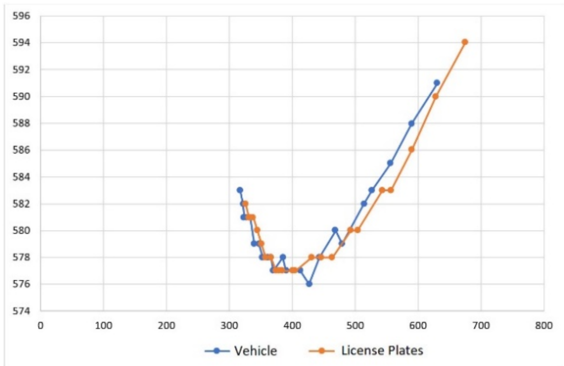


Fig. 5. Statistic of centroids of license plates and that of vehicle objects detected

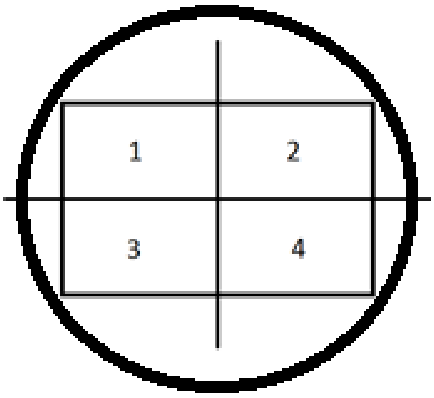


Fig. 6. Magnified image sensor structure

Let consider the effect of the opening and closing shooter time (ST), i.e. exposure time on the stated problem of vehicle speed detection as follows. Highway system in Vietnam entirely allows speed up to $120 km/h$ at night, that is equivalent to about $33.33 m/s$. However, in previous studies, especially in [6], this issue was mentioned but not resolved because of the system implementation context in typical urban areas rather than highways. Therefore, some typical surveillance cameras are unable to capture vehicles moving at high speed, hence the opening and closing ST time may significantly affect the accuracy of the speed detected.

Looking back to Fig. 1, the surveillance camera used in the system to collect data operates at 12 fps at a resolution of 1280 x 720 pixels. Normally, the opening and closing ST to capture high-speed movement is typically designed at 1/8000s.

That means the travelled distance of a given vehicle detected per frame is around 33.33⁄12 m. In this case, it is easy to see that the error in speed detection without consideration of ST is equivalent to about 8.33% at speed of 120 km/h or 33.33 m/s. This error is even greater for blurred frames in the acquired video sequence as well as processing steps in speed detection workflow. If the ST is opened longer or at least long enough to capture a frame at a given speed, the image will be blurred followed by such a called media trail. This may lead to incorrect box detection covering the vehicle or its license plate.

3. Results and Evaluation

3.1 Simulation Scenario

The traffic data are acquired on highways and streets of an inner city and prepared for performance evaluation of the proposed method. The traffic data from the surveillance camera system implemented on Phap Van - Cau Gie Expressway and Quan Su Street in Hanoi city are retrieved from the centralized monitoring system. The simulation data is collected in the morning time without rain and sunshine. The surveillance camera's setting parameters are given in Table 1.

3.2 Simulation Results

The modeling in [6] is reutilized herein in the proposed method, however with consideration of opening and closing ST of the camera to enhance the accuracy of vehicle speed detection speed. Thanks to the control of this ST of the surveillance camera, one can see that both vehicles and their license plates have been identified and localized on both highways as well as in inner streets.

Table 1. Surveillance camera setup and its parameters

Camera mounted height relative to the road surface	6.15 m
Elevation angle	78.7 degrees
Vertical scanning angle	37.4 degrees
Focal length	4 mm
Resolution	1280 x 720

Table 2. Comparison of the results of the proposed method and the method in [5] (km/h) for highways

No	Samples	Detected speed by the proposed method	Detected speed by method in [5]	Detected speed by GPS
1	Samples 1	88.4	86.4	89.75
2	Samples 2	85.6	83.5	86.15
3	Samples 3	90.3	89.3	90.74
4	Samples 4	80.7	80.5	81.05
5	Samples 5	86.4	85.3	86.77
6	Samples 6	90.7	88.6	91.05
7	Samples 7	89.5	87.4	90.18
8	Samples 8	83.4	82.3	83.66
9	Samples 9	89.9	88.3	90.11
10	Samples 10	87.6	87.1	87.85

3.3 Results and Performance Evaluation

Table 2 summarizes the detected speeds by applying the proposed method and that of the work in [6]. Herein, 10 samples are taken from the traffic databases including different vehicles on Phap Van – Cau Gie highway and moving at different speeds. Meanwhile as demonstrated in the third column of Table 2, considering the detected speeds to that measured speed by the installed GPS in a vehicle which appears in the captured video sequence, the results imply the significant improvement in terms of speed detection accuracy thanks to the controlled ST, which is small enough in this case. In addition, the higher resolution of the acquired frames also contributes to better accuracy of seed detection process.

Fig. 7. Demonstration of detected vehicles with theirs license plates bounded by the red boxes from the consecutive frames in video sequence acquired on Phap Van – Cau Gie Expressway

Fig. 8. Illustration of detected vehicles from a mixed traffic flow acquired on Quan Su street

In analogy, Table 3 demonstrates the result comparison in the speed detection process implemented by the proposed method, previous work in [6] and GSP system inside vehicles that join in a mixed traffic flow on Quan Su Street. This performance proves that the proposed solution is applicable to monitor vehicle speeds moving on highways as well as streets.

The detected vehicles from the video sequence are demonstrated in Fig. 7 where a truck and bus are coming from a distance, then captured by the surveillance camera and its speed is detected from the measured centroid movement of the license plate throughout consecutive frames.

Fig. 8 illustrates another transportation scenario in Quan Su Street in Hanoi, where a mixed traffic flow from different types of vehicles such as motorbikes, cars… is recorded by a surveillance camera. One can see that all vehicles in this traffic have been identified including license plates of cars that have been tracked out. The centroid movement of tracked boxes in consecutive frames has been effectively utilized to monitor the speed of each vehicle appearing in the video sequence, because of the exact vehicle's position the duplicated centroids of vehicles and license plates detected.

These results again imply that the modeling in [6] is not suitable for high-speed vehicles such as in highways if the opening and closing ST which have been studied in this work are not taken into account. Fig. 9 illustrates the camera's shutter, which can be maximum opened to X_{max} position for a given frame in a very short interval of time. Investigation of the opening and closing ST is helpful to overcome acquisition of blurred images for a given surveillance camera, and then enhance the frame quality which leads to better performance in vehicle and plate localization and then speed detection. Therefore, the control of opening and closing ST will help determine the exact moment the shutter starts to acquire frames and then localize more precise position of vehicle on road.

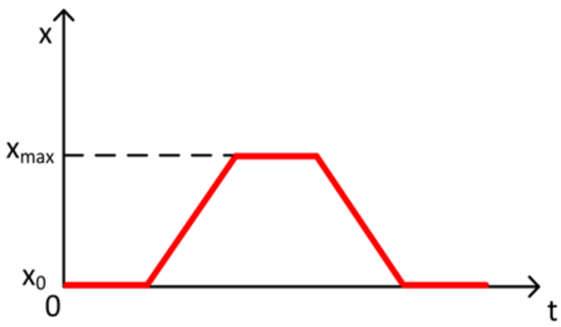


Fig. 9. Illustration of opening and closing ST for a given frame

The speed detection error in [6] is about 8.33% compared to that of the detected by GPS speed mounted in the vehicle. The reason mainly comes from the blurriness of the acquired video sequence of the surveillance cameras. Utilization of ST in this work helps to reduce the blurriness and therefore improving the monitor of vehicle speeds.

Table 3. Comparison of the results of the proposed method and the method in [5] (km/h) for inner-city streets

No	Sample	Detected speed by the proposed method	Detected speed by method in [5]	Detected speed by GPS
1	Samples 1	28.01	27.84	28.06
2	Samples 2	25.64	24.43	25.83
3	Samples 3	24.57	23.68	24.68
4	Samples 4	41.35	39.99	41.69
5	Samples 5	4.56	3.96	4.58
6	Samples 6	35.05	34.18	35.32
7	Samples 7	37.63	36.91	37.66
8	Samples 8	15.09	14.81	15.15
9	Samples 9	12.23	11.72	12.32
10	Samples 10	24.11	23.44	24.30

6. Conclusion

This paper focuses on modification of research work proposed in [6] to improve the speed detection accuracy on highways, which investigates the effect of opening and closing ST of the system surveillance camera. In addition, the proposed method shows better performance utilizing centroid information of the vehicle's license plate instead of vehicle recognition.

The future work will concentrate on determination of vehicle speed in dark conditions investigating vehicle's headlights and taillights.

Acknowledgments

This work is supported and funded by Hanoi University of Science and Technology under project code T2018-PC-218.

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