Vehicle Velocity Estimation for Traffic Surveillance System

H. A. Rahim, U. U. Sheikh, R. B. Ahmad and A. S. M. Zain

Abstract—This paper describes an algorithm to estimate real-time vehicle velocity using image processing technique from the known camera calibration parameters. The presented algorithm involves several main steps. First, the moving object is extracted by utilizing frame differencing technique. Second, the object tracking method is applied and the speed is estimated based on the displacement of the object's centroid. Several assumptions are listed to simplify the transformation of 2D images from 3D real-world images. The results obtained from the experiment have been compared to the estimated ground truth. From this experiment, it exhibits that the proposed algorithm has achieved the velocity accuracy estimation of about ± 1.7 km/h.

Keywords—camera calibration; object tracking; velocity estimation; video image processing

I. INTRODUCTION

THE rapid urban sprawl in most parts of the world has resulted in the increment of traffic congestion where it demands a high reliable traffic management system for monitoring the traffic flow [1]-[3]. Traffic management system has been part of Intelligent Transportation System (ITS) applications that provides crucial input parameters such as lane occupation and average velocity for traffic flow prediction [2]- [3]. However, more information about the variation of the velocity distribution of the vehicles is also needed in order to estimate the occurrence of traffic congestion [2].

The common method to obtain information on traffic flow is by utilizing buried induction loops. Although this existing technique is not affected by weather and light conditions, it suffers from high installation and maintenance costs [2]-[3]. In order to overcome this limitation, vehicle tracking using image processing techniques has been adopted for traffic monitoring system to yield the traffic parameters including queue detection, incident detection, lane changes, vehicle classification, vehicle counting and vehicle speed [1]-[4],[11]. A more reliable traffic flow modeling and an improved understanding of drivers' behavior can be attained since the vehicle tracking system can provide more individual vehicle data such as spacing, velocity and acceleration [1].

Several techniques of vehicle tracking system have been investigated for traffic monitoring [1]-[9]. Coifman et al.

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[1] reported the use of network of DSPs combined with Pentium processor to calculate the vehicle speeds and compared the results to 5 minutes average traffic speed. Another approach to measure the speed of the vehicle is to use a complex scalable

multiprocessor architecture [5]. Although this work performs good results, it is not feasible because of a very high computational cost. Bauer et al. [2] and Litzenberger [6] proposed new tracking technique that used an asynchronous temporal contrast vision for high speed vision and compared to calibrated light barriers system as reference. In [4], [7]-[8], a new algorithm to compute traffic speed utilizing uncalibrated cameras to remove perspective effects were presented. Ab-Rahman et al. [9] introduced velocity estimation algorithm using stereoscopic vision that used two cameras. However, this proposed algorithm required a precise calibration of two cameras in parallel optical axes to obtain accurate results. The authors in [10] reported vehicle tracking technique with speed estimation and the results were compared to GPS receiver system.

This paper describes a proposed system of real-time video based velocity estimation that includes vehicle detection, vehicle counting and individual vehicle speed estimation. The proposed system first extracts the moving vehicle using frame differencing techniques. The moving object is tracked and the speed is computed based on the displacement of the object's centroid using kinematics equations. The calibration between pixel distance and real world distance traveled has been done to overcome perspective distortion. With this method, accurate velocity can be estimated independent of the position of the object relative to the camera. The accuracy of velocity estimation is obtained by comparing to the average traffic speed.

The paper is organized as follows. Section 2 addresses the assumptions made to simplify the vehicle tracking problems and Section 3 explains a detailed description of procedure to estimate velocity of the individual vehicle. Section 4 exhibits the velocity estimation results that are compared to the average of traffic speed. Section 5 gives conclusion to the presented work.

II. ASSUMPTIONS

Assumption should be made since the images only represent 2D coordinates which are actually the 3D coordinates in the real world scene. In order to overcome this problem, some assumptions are made as follows:

1. The camera calibration parameters are known.
2. All vehicles move on a flat known ground plane.
3. The vehicles movements are forward in all cases where no perspective distortion occurs. The length in pixels and the distance in world coordinate are linear [11]-[13].

Bounded by these assumptions, the simulation of the actual projection of the real world scene to the screen space can be made by using perspective projection and ground plane calibration to recover the depth information of moving object. Besides that, a linear function of perspective distortion makes the proposed technique feasible to determine the distance traveled in real-world and thus leads to the computation of the vehicle velocity. The proposed system is also restricted to the certain conditions where this system only considers daylight condition and non occlusion handling task.

III. ALGORITHM DESCRIPTION

(a)   (b)

Fig. 1 Video images from CCTV camera from upper left: (a) captured event of image in colour (b) converted image in grey scale

This section highlights the overview of algorithm procedure in obtaining the estimated velocity of moving objects. CCTV camera with resolution of 25 frames/sec is used to operate the algorithm. Several steps are taken to process the captured images before determining the vehicle velocity. First, colored images are converted into grey scale. A reference background image from video stream is generated, as shown in Fig. 1 (a) and (b).

Second, at any time, the moving object is extract from the scene by first subtracting the current frame with the reference frame. The frame differencing technique has been employed to detect the motion of an object. $I_r(x, y) \in Z^2$ with a video frame size of m x n, I = $(0 \le x < m, 0 \le y < n)$. Thus, frame differencing can be defined as [12]:

$$D_\tau = \arg \max(I_\tau - I_{\tau-1}) \qquad (1)$$

After the differencing the image frames, the reference background image is updated for any changes in illumination and etc. The extracted moving objects are thresholded with the predefined threshold value to acquire binary image [4].

The resultant images are filtered by performing repetitive erosion and dilation. After the morphological operations, the remaining objects are then filled using region filling algorithm to remove any holes in the object as small spurious objects have been removed from the previous steps. Then, the

centroid of each object is computed and then tracked. The results of these step-by-step preprocessing techniques are illustrated in Fig. 2 (a) – (d).

Vehicle motion in the images is represented by the moving blobs.

(a)   (b)

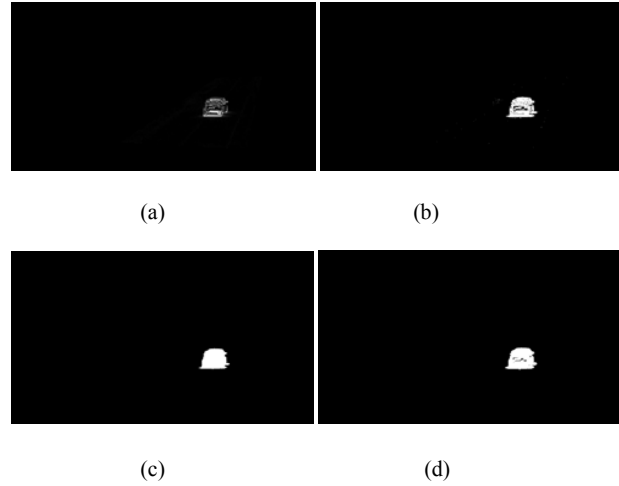(c)   (d)

Fig. 2 Preprocessing images from upper left: (a) result of frame differencing technique (b) image is thresholded to acquire binary image (c) undergo morphological cleaning and noise reduction processes (d) result of region filling

Centroid is computed by calculating the blob's spatial moment and is given in (2) and (3) [11], [13].

$$u_{pq} = \sum_{x_b=0}^{m-1} \sum_{y_b=0}^{n-1} x_b{}^p y_b{}^q : (x_b, y_b) \in b, \forall b \in \mathrm{B} \qquad (2)$$

$$x_{cb} = \frac{u_{10}}{u_{00}}, y_{cb} = \frac{u_{01}}{u_{00}} \qquad (3)$$

The velocity is computed by computing the difference between the centroid at time t and t-1 divided by the frame rate. This velocity in pixels per second is later converted to km/h based on the known camera calibration values. Fig. 3 demonstrates the resultant images from these procedures.

IV. ACCURACY ESTIMATION

The experiment has been carried out on a selected road lane, just outside the lab building. The camera is set up to face the lane with a downward tilt of 20-25˚. The finite temporal resolution of the camera is 25 frames/sec with frame dimension of 384 x 288 pixels. The velocity measurement is taken for every 5 frames/sec that is equal to 200 msec.

An estimation of the accuracy of vehicle velocity is constrained by the timing resolution and displacement resolution in pixels on the images. Since the inductance loop speed estimation is currently unavailable in south region of Malaysia's PLUS highway, the algorithm accuracy is evaluated by comparing to the ground truth estimate of the individual vehicle speed. The ground truth reference values,

tabulated in Table I are acquired by computing the average estimated velocity from the image frames of region of interest (ROI). The image frames are divided into 3 equal intervals

which are upper, reference and lower. The ground truth estimated velocity for individual vehicle is obtained by taking
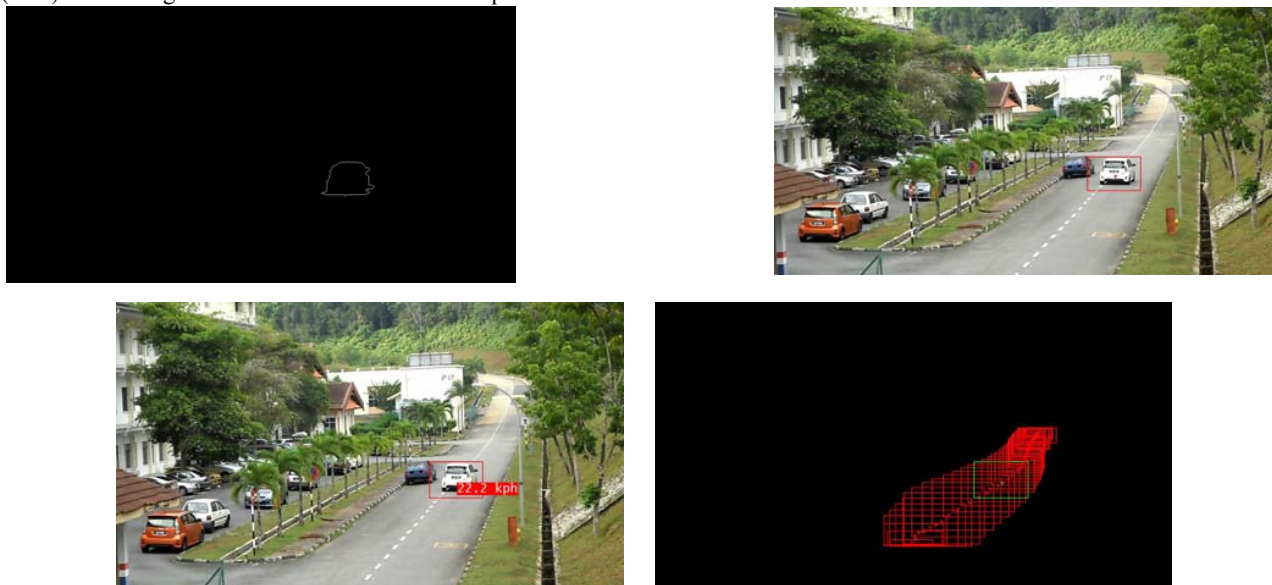

Fig. 3 Image sequence from upper left: (a) object shape extraction for centroid computation (b) centroid is pointed by red mark in ROI rectangular shape (c) speed computation as displayed in the image (d) continuous tracking with green box as current frame referred in previous images

the average velocity of start frames and end frames at each interval. Five vehicles which pass through the ROI are tracked over 30 minutes.

The estimated individual velocity is then compared to the reference interval values as this interval lies in the centre of ROI and it provides more accurate mean speed compared to the other intervals. The error between the estimated individual velocity and the ground truth for 5 tracked vehicles is presented in Table II.

TABLE I
COMPARISON OF ESTIMATED GROUND TRUTH AND ESTIMATED RESULT

| | Frames | | | Average speed (km/h) |
	Start frames (i)	End frames (i)	Total frames	
Reference (Car 1) Upper	35	105	70	16.9
Reference (Car 1)	105	175	70	22.5
Reference (Car 1) Lower	175	245	70	21.8
Measured (Car 1)	105	175	70	23.1
Reference (Car 2) Upper	1925	2015	90	16.2
Reference (Car 2)	2015	2110	95	16.0
Reference (Car 2) Lower	2110	2200	90	17.7
Measured (Car 2)	2015	2110	95	16.5
Reference (Car 3) Upper	2670	2745	75	11.5
Reference (Car 3)	2745	2825	80	13.4
Reference (Car 3) Lower	2825	2905	80	15.1
Measured (Car 3)	2745	2825	80	19.4

Reference (Car 4) Upper	4455	4515	60	22.0
Reference (Car 4)	4515	4575	60	23.8
Reference (Car 4) Lower	4575	4635	60	19.6
Measured (Car 4)	4515	4575	60	23.8
Reference (Car 5) Upper	4725	4795	70	19.9
Reference (Car 5)	4795	4870	75	25.1
Reference (Car 5) Lower	4870	4940	70	16.4
Measured (Car 5)	4795	4870	75	23.5

TABLE II
ERROR MEASUREMENTS OF FIVE TRACKED CAR

Tracked vehicle	Error (km/h)
Car 1	0.6
Car 2	0.5
Car 3	6.0
Car 4	0.0
Car 5	-1.60

The result in Table II exhibits that the average error produced by the estimated velocity is 1.7 km/h. Highest estimated error value is produced by the third car that contributes error of 6 km/h. This may be due to the inconsistent speed of that tracked car. Therefore, the experiment performed in this paper demonstrates that the proposed system may obtain an estimated accuracy of velocity around ± 1.7 km/h. The validity of the proposed system will also be done with GPS system on a moving car [10].

V. CONCLUSION

An algorithm to estimate a real-time velocity of a moving vehicle using the known camera calibration parameters is discussed this paper. The development of the proposed algorithm involves several major steps; detecting moving object using frame differencing technique, tracking the detected moving object using an adapted point-based tracking algorithm and computing the estimated velocity based on the displacement of object's centroid. In order to simplify the algorithm, several assumptions have been made as mentioned in Section II.

Based on the experimental results, it demonstrates that the proposed algorithm is capable of estimating the vehicle velocity from a single uncalibrated camera. The velocity estimation error has been evaluated by performing comparison to the ground truth. The accuracy of about ±1.7 km/h for individual vehicle velocity has been accomplished. However, the algorithm has not yet been validated with reference system, such as GPS system. The accuracy of vehicle estimation will further be obtained by comparing to the reference system and other related work. Thus, a more accurate uncertainty in velocity measurement for any moving vehicle can be determined.

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