Single Camera Vehicles Speed Measurement

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***Abstract*—Image and video processing techniques are one of the commonly used methods for traffics monitoring. This paper investigates the image processing techniques based vehicles speed measurement issue using only a fixed single camera. Therefore, a geometrical calculation based method is proposed. Based on this method, first a moving vehicle is detected in a video background and then the vehicle speed is estimated based on some geometrical calculations. A comparison is made between this method and two other same case vehicles speed measurement methods for evaluation. The simulations results on 160×112 pixels real recorded video images shows the average vehicles speed error less than %10.**

***Keywords*—Image Processing Techniques; Vehicles Speed Measuremen; Traffic Monitoring;**

I. Introduction

Nowadays, the most countries all over the world are confronted with the traffic problems. In the past decades, the traffic engineers were investigating the methods to obtain information on the roads usage for determining of the areas in need of expansion or requiring alteration of existing traffic patterns. But recently interests have focused on the warning systems which alert drivers about heavy congestion or accidents further ahead on the road. Such systems require real the time performance [1].

The traffic engineering is applied to decrease of accidents, congestion and delay as well as increase of security. Integrated and suitable traffic control equipments such as traffic signs, traffic lights, and highways entry, are significantly used for improving of the traffic quality [1]. The vehicles speed values are one of the most important necessary parameters for the traffic engineering [1].The radar, sonic and optical (vision) based systems are commonly used equipments to estimation of the vehicles speed values [1-7]. Using vision based systems need to utilization of the image processing techniques to detect a vehicle in the video images background and estimate the vehicle speed value based on the different methods. Another requirement of such real time traffic monitoring system is that the vision processing system must be robust to vibration of the camera to estimate the vehicles speed values accurately [1]. Most of the previous relative researches have considered the traffic monitoring as a model based tracking problem. Therefore, they have performed a full 3D analysis to extraction of the vehicles information as types and speeds [1-6]. In this paper, a method is proposed which utilize the digital video images, uses the image processing and machine vision techniques for detecting the speed value of a vehicle based on using only a single camera.

II. The Proposed Vehicles Speed Measurement Mrthod Steps and The Simulations

For real time estimation of the moving vehicles speed values using the video images, first, there is need to detect the moving objects in the consecutive frames and then, calculate the speed of each detected object. There are used some image processing techniques for both steps. Follows, the used image processing and geometrical calculation techniques in the proposed method are presented.

A. The video images background estimation

Generally, background estimation refers to finding a frame in a video image without including moving objects. In this paper, the background video image obtaining is based on this assumption that during a lot of consecutive video images, for each pixel, the times that the brightness of the scene is observed, are more than the times that there is some moving objects in it. Therefore, using some techniques as average taking of all consecutive frames, can obtain a picture of blank scene. This method which is often used for applications with a fixed camera is the most widely used method for recognition of the moving objects (motion detection) and especially, gives accurate results for environments with low light variations. Equation (1) is used as the average taking technique for the video images background extraction:

$$K_i = \frac{(\mathrm{i}-1)\times K_{(i-1)}+\mathrm{f}_i}{\mathrm{i}} \quad \mathrm{i} = 2,3,4,\ldots \tag{1}$$

where f_i is the measure of pixel (x,y) in i^{th} frame, k_i is the pixel average (x,y) to i frame. In accordance with the background estimation method which is based on the scene brightness variations, there is need a model based on brightness variations of color. For this purpose, there is need to use the HIS model. This color model is simulated in this paper using Matlab software, where HIS model is defined in Matlab software as HSV model. Therefore, for background estimation in the video images, there is used the HSV color model instead of RGB one (Figure 1).

B. Detection of The Moving Objects

For detecting a moving object, the conventional method is the subtraction of two consecutive frames from each other method. This method creates distance between the moving object or causes an object to be recognized as multiple objects in upper frames or high speed of moving object (Figure 2). Therefore, the use of subtraction of background from considered frame method can be better than it.

For detecting the moving objects in this method, the third column of the (severity of color's brightness) HSV model images matrixes, meaning color's brightness, is used (Figure 3). In this mode, objects with bright and shiny surface have good resolution and they are recognizable. But, the objects with dark surface are not recognizable by the third column of the HSV model matrix, putting difficulty before algorithm later. Therefore, the second column of the HSV model matrix (color saturation) is used (Figure 4) for the state in picture of both the bright and the dark scenes. Then they are used the addition of the third and second columns of the HSV model matrix (Figure 5).

C. *Detection of the borders*

After detection of the moving objects, for simplification of process and obtainment of the boundary of each moving object with surroundings and the center of moving object, first there is need to convert all color images to binary images, and then the gaps in the binary images should filled. Finally, the noise and small spots on the images should be removed (Figure 6).

In this paper, some extractable features of each moving object should be obtained in order to measuring of the speed. For this purpose, first, the border of each moving object is obtained, and then this border is used for enumeration and categorization of the vehicle types. However, the basic function of this border in this paper is to obtain the center of the moving object. The obtained values are directly used for measuring of the vehicles speed. Each border can be approximated by fitting a polygon and with arbitrary precision. Regarding to the closed curves, this approximation is precise when the number of polygon's sides is the same as the border points numbers in such a way that each pair of the adjacent points specify one side of the polygon.

In practice, the aim of approximation of the polygon is to obtain the general form for border with the least possible line segments, which is not generally simple and may lead to a long repetitive search. However, there are a few methods for approximating of the polygon which are not complex and need a little processing and are suitable for processing the images. These methods are finding the polygons with minimum perimeter. For example, suppose the surrounding border in a set of connected cells of the detected object. It's better to imaging this fence as two walls corresponding to external and internal borders of cells' strip. If the rubber strip is contractile, it will become the Figure 7, if this cell contains only one border point, maximum error between the initial border and approximation of rubber strip in each cell would be $\sqrt{2d}$, where d is the distance between the pixels. By displacing each cell in a way that its center is adapted to its corresponding pixel, upper bound of this error is halved [7].

After extraction of the moving object's border, the moving objects are labeled, which are used in enumeration of each vehicle and obtainment of each object's coordinates.

Figure 1. Background Estimation in The Video Images

a) b) c)

Figure 2. a) The resulted image from subtraction of two consecutive video images b) and c)

Figure 3. Detection of the moving objects using the color's brightness amount

Figure 4. Detection of moving objects using color saturation

Figure 5. Detection of the moving objects using addition of color intensity and color saturation

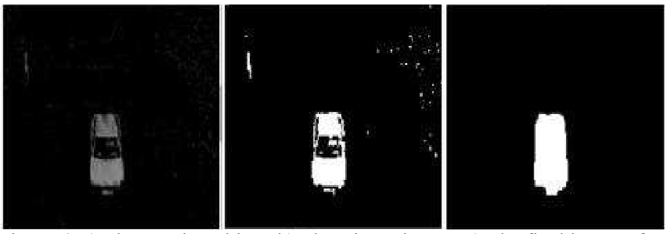

Figure 6. a) The Moving object, b) The Binary image, c) The final image after removing noisy pixels and filling gaps

Fig. 7. Extraction of the borders and obtainment of the object center

D. Estimation of the vehicle speed value

For measuring the speed value, the equation of displacement in time domain is used as:

$$v = x/t \qquad (2)$$

- *Measuring displacement in terms of pixel*

In this step, for measuring the speed value, it is necessary to obtain the displacement in terms of the pixels number. For this purpose, it would be enough to subtract the object's center in two consecutive frames from each other, leading to following three states:

Number of the detected moving objects in i^{th} frame and $(i-1)^{th}$ frame are the same. In other words, the rows values of the both matrixes of two frames are the same. Therefore, each row of $(i-1)^{th}$ frame is subtracted from the every row of i^{th} frame. However, it's possible that the detected moving object in $(i-1)^{th}$ frame goes out of the image at the same time and another object enters to the image in i^{th} frame (the number of rows is the same as each other). For solving this problem, another condition was made, which is that the second component of the object's center in i^{th} frame must be greater that the center of the same object in $(i-1)^{th}$ frame. Otherwise, the differential between those rows is not done in two consecutive frames. For example, if the matrix of centers of i^{th} frame and $(i-1)^{th}$ frame are as follow:

$$i = \begin{vmatrix} a & b \\ c & d \end{vmatrix} \qquad i-1 = \begin{vmatrix} e & f \\ g & h \end{vmatrix} \qquad (3)$$

where the number of rows is the same as those of the moving objects in the image, if there is $b > f$, the displacement of the first object is:

$$d_1 = \sqrt{(a-e)^2 + (b-f)^2} \qquad (4)$$

and if there is $d > h$, the displacement of the second object is:

$$d_1 = \sqrt{(c-g)^2 + (d-h)^2} \qquad (5)$$

If the number of detected moving objects in i^{th} frame is more than those in $(i-1)^{th}$ frame, the number of rows of matrix of centers in i^{th} frame is more than that of rows of matrix of centers in $(i-1)^{th}$ frame (one object has entered to the image in i^{th} frame for the first time). If the matrix of centers values of $(i-1)^{th}$ frame has n rows and the matrix of centers values of i^{th} frame has m rows, and if there is $(m > n)$, In this case, for obtaining the displacement value, the differential between j^{th} row of the matrix of centers values of i^{th} frame and j^{th} row of the matrix of centers values of $(i-1)^{th}$ frame is computed in which j is as follow:

$$\mathrm{j} = 1,2,3,\dots,\mathrm{k} \text{ where } i = \begin{vmatrix} a & b \\ c & d \\ e & f \end{vmatrix} \text{ and } i-1 = \begin{vmatrix} g & h \\ k & l \end{vmatrix} \ (6)$$

The third row ($[e \quad f]$) is due to the first time entrance of the object to i^{th} frame. The number of the detected moving objects in the frame is less than those in $(i-1)^{th}$ frame. In other words, the number of rows of the matrix of centers values in i^{th} frame is less than the number of rows of the matrix of centers values in $(i-1)^{th}$ frame (an object which has been in the image in $(i-1)^{th}$ frame has gone out of the image in i^{th} frame:

If the matrix of centers values of $(i-1)^{th}$ frame has k rows and the matrix of centers values of i^{th} frame has l rows in which $(k > l)$ and $k - l = r$, In this case, for obtaining the displacement value, the differential between j^{th} row of the matrix of centers values of i^{th} frame and $(j+r)^{th}$ row of the matrix of centers values of $(i-1)^{th}$ frame is computed where j is as follow:

$$j = 1,2,3,\dots,l \qquad (7)$$

- *The Camera's field of view*

The time that a moving object enters to an image, due to existence of the large distance between this object and the camera, its dimensions seem small. With decrease of the distance between the moving object and the camera, these dimensions seem larger, leading that the displacement value of the object changes pixel by pixel with changing of the distance between the object and the camera in the consecutive frames. The times that the moving object closes to the camera, the displacement value between the two consecutive frames increases pixel by pixel. For measuring this effect, it's necessary to compute the camera's field of view (FOV) angle (Figure 8).

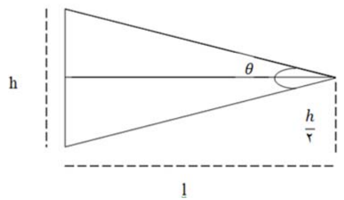

Figure 8. Sideview of the camera's field of view

If φ is the camera's viewing angle, it can be calculated as:

$$\varphi = 2\tan^{-1}\frac{h}{2l} \qquad \varphi = 2\theta \qquad (8)$$

- *Calculation of the speed value*

As mentioned, the detected moving object displacement value is equal to the calculated the difference pixel numbers between the two consecutive frames. Therefore, the moving vehicle speed value is calculated using the difference pixel numbers and the elapsed time between two consecutive frames. The displacement value is calculated using the equation (4). Due to using a 25 frame rates fixed camera for recoding the real video images, the elapsed time between the two consecutive frames is 40 millisecond. Also due to the camera's FOV, the displacement is calculated in relevance with the difference pixel numbers. Hence, the moving vehicle speed is computed. But there is an angle between the fixed camera and the road or street (Figure 9). Therefore, there is need to correct the calculated moving vehicle speed value in relevance with this angle effect on the video images. The equation (9) is used for this correction. Using this equation, real 3-D visual image is mapped on the camera image.

$$v' = v\cos\theta \quad v = \frac{v'}{\cos\theta} \tag{9}$$

where v is the unmapped moving vehicle speed, v' is the real and mapped moving vehicle speed and θ is the angle between the horizon's line and the line crossing the center of camera and the vehicle.

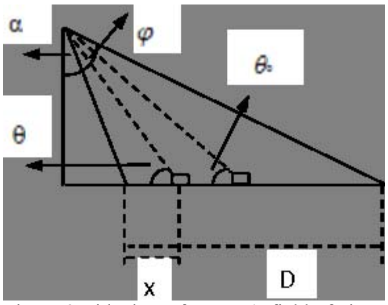

Figure 9. sideview of camera's field of view

Obtaining the real value of θ is difficult. Therefore, it should be approximated. This approximation is precise the times that the detected moving object center is close to the center of the image. But it's with some errors when the detected moving object center is not close to the center of the image. When the detected moving object center is close to the center of the image, θ is approximated using:

$$\theta_0 = 180 - \left(\frac{\varphi}{2} + \alpha + 90\right) \qquad \theta = \theta_0 + \frac{x}{D}\varphi \tag{10}$$

III. Algorithm of the proposed method

According to section II, the algorithm of the proposed moving vehicles speed measurement method is as follow:

1. Fix a camera on a road or street with a approximated angle
2. Record real time video images frame by frame
3. Convert color model of all consecutive image frames (RGB color model to HSV or HIS color models)
4. Estimate of background in all consecutive frames
5. Detect all moving object
   a. Detect borders
   b. Fill the gaps and reduce the noise pixels
6. Is there a moving object?
   a. Yes, go to step 7
   b. No, go to step 2
7. Calculate the moving objects displacement values
8. Calculate the moving objects speed values
9. Goto step 2

IV. Disscusion on The Simulations Results

According to section III, the proposed method was simulated as section II and was compared with the three other same case vehicles speed measurement methods. The simulation results of the proposed method are presented in table I. According to table I, the average error is less than %10.

Table I. Comparison of the obtained results with the real speed values

Real Speed Km/h	Obtained Speed Km/h	Error km/h
40	35.4530	4.547
50	48.9310	1.069
60	55.8359	4.1641

In the proposed method in [3], some points have been considered to test on the image, and when the vehicle crosses these points, speed is computed. In comparison with our proposed method, this method has approximately a high precision. In the proposed method in [5], the camera has been placed in a vertical manner, which has an advantage over our proposed method, which is the reduction of complexity of measurements for obtaining camera's angles and fields of view. In the proposed method in [6], the results show that the proposed models have a relatively acceptable performance and are able to obtain the speed with an accuracy of $\pm 10\%$. But occasions for bad weather such as heavy fog, weak illumination and night scenes have poor performance. The main problem under these conditions is the inaccurate detection of vehicles.

V. Conclusion

In this paper, an image processing based method was proposed for measuring the speed of the moving vehicles in the recorded video images by a single camera. In this method, first the background was estimated based on the brightness intensity of color, then, the moving object in the consecutive image frames was detected, and finally, the speed of the moving objects were measured based on some geometrical calculations. In this method, all steps were done for the normal weather circumstances. There is this capability in the future that this method can be modified which is applicable in day and night or bad weather conditions.

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