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Semi-Geometrical approach to estimate the speed of the vehicle through a surveillance video stream

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***Abstract*—**For the past few years reducing road accidents and controlling traffic by limiting the speed of vehicles has gained more importance. Most of the methods so far used are Doppler radar, IR or Laser sensor based speed calculation. All of them are very expensive and also their accuracy is not quite satisfactory. In this paper, a Camera-based Speed Calculation System(CSCS) is employed, CSCS uses image processing techniques and can process video stream in online or offline mode, CSCS has the ability to determine the speed with good accuracy but at relatively low cost. In this study, the acquired video is pre-processed to remove the redundant information, then foreground information is extracted from the video. After this noise and shadow are removed from the video. Moving vehicles are localized and centroid for them are found out. Region Of Interest(ROI) box was constructed for each lane. Speed is calculated with the help of Distance Speed Time formula by counting the number of frames taken by the vehicle to pass through the ROI box. A database in the form of the log file is created which contains vehicle speed, location(vehicle has passed from which CSCS system), time at which this speed was recorded and whether it has crossed the speed limit or not. CSCS was tested and has achieved satisfactory performance with an accuracy of 95.44%-99.64%.

***Keywords*—** Camera-based Speed Calculation System(CSCS), Background subtraction(BS), Localization, Centroid, Region of interest(ROI), Database, Automatic Number Plate Recognition(ANPR) system.

I. INTRODUCTION

According to the Indian Ministry of Road Transport & Highway, Global status report on road safety 2013 road accident statistics over 1,37,000 people were killed in road accidents in 2013 alone, which is more than the number of people killed in all our wars put together. Overspeeding is the major cause of car accidents that increases the risk of injury or death. According to the Governors Highway Safety Association Texas, overspeeding is a major factor in approximately a third of all traffic fatalities. It also plays a serious role in major injuries caused by car accidents. Therefore vehicle speed regulation is one of the most crucial carries out of the traffic laws.

For determining the speed, Doppler radar was a reliable device as long as there was no other vehicle in the field of view. That's why the proposed study uses the Image Processing technique with the help of CSCS to accurately measure the speed of the approaching vehicle. Initially, the system was developed with a laptop and a mobile camera. The aim was to deploy the developed software into a compact system such as Raspberry Pi. CSCS can be integrated with the ANPR system to form a complete system.ANPR uses Optical Character Recognition (OCR) to extract the number plate characters of the vehicles and by doing so we can track the vehicles which are found breaking the speed limit.

Rest of the paper is organised as follows: Section II presents the System Design and Implementation followed by Section III which presents the Experiment and Results. Section IV concludes this paper.

II. SYSTEM DESIGN AND IMPLEMENTATION

For accurate speed measurement camera placing becomes an important aspect. In our study camera is set up such that it records the front view of the approaching vehicle. The camera used in the study has a frame rate of 30fps. A frame is captured at every 33.3ms, the pixel size of the camera is 1.12 um Aperture and the focal length is f/1.7, 27.22mm. Perspective distortion on the acquired video was not considered in our study. Figure. 1 shows the block diagram for system architecture.

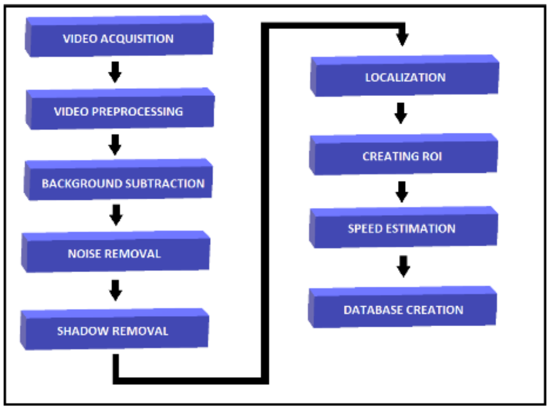


Figure 1. System Architecture for CSCS

A. Video Acquisition

Figure 2. shows the placing of the camera. For determining the length of the ROI box for speed calculation, we need to define a ratio that measures the number of pixels per given metric. We call this " pixels per metric " ratio.

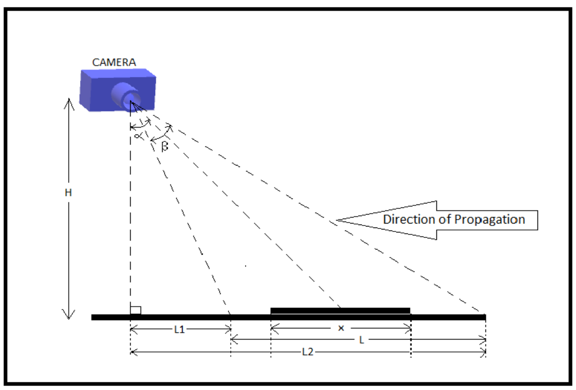


Figure 2. Video capturing design

Here, β = field of view (FOV) of the camera, α = angle of the camera, x = length of the ROI box, h = camera height from the ground.

FOV can be calculated with:

$$\beta = 2 \times \tan^{-1}\left(\frac{d}{2f}\right) \qquad (1)$$

Here, d = represents the size of the film (or sensor) in the direction measured, f = effective focal length.

Pixels per metric can be written as:

$$\text{Pixels per Matrix} = \frac{\text{Object width}}{\text{Actual width}} \qquad (2)$$

Where object width is measured in pixels which can be calculated from the video

.

$$L1 = h \times \tan\left(\alpha - \frac{\beta}{2}\right) \qquad (3)$$

$$L2 = h \times \tan\left(\alpha + \frac{\beta}{2}\right) \qquad (4)$$

The actual width of L(length of the field of view of the camera) can be found out as :

$$L = L2 - L1 \qquad (5)$$

Actual width of x

$$= \frac{\text{Object width of x} \times \text{Actual width of L}}{\text{Object Width of L}} \qquad (6)$$

Thus with the help of camera specifications and camera height from ground, we can find the length of the ROI box.

B. Video Pre-Processing –

In our study, we have placed a single camera for addressing one-way traffic. Thus it becomes necessary to remove redundant parts present in the video before feeding it to the algorithm, so as to increase the efficiency by reducing processing time. Equation(7) is used for this, Figure 3(a) represents the snapshot of the actual video recorded and Figure 3(b) represents the snapshot after the pre-processing step.

$$I_{new}(x, y) = I_{old}(0 \le y \le y_T, x_1 \le x \le x_T) \qquad (7)$$

(a)

(b)

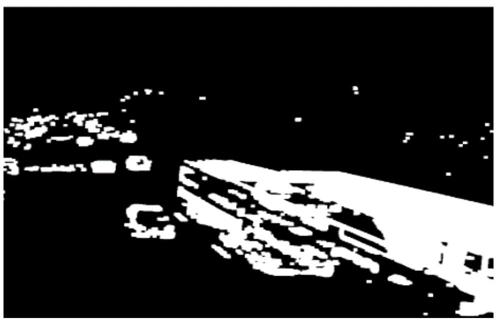
Figure 3 (a). Before pre-processing (b). After pre-processing

C. Background Subtraction –

BS is a technique that allows a video foreground to be extracted for further processing. It helps us for detecting moving objects in the video from the static camera. It calculates the foreground mask performing a subtraction between the current frame and a background model, containing the static part of the scene. Equation(8) is used for background subtraction, Figure 4(a) shows the snapshot taken after the pre-processing step and Figure 4(b) represents the snapshot taken after the Background Subtraction.

$$I_{bg} = | I_{current} - I_{stationary} | \quad (8)$$

(a)



(b)

Figure 4 (a). Original image (b). Image after background subtraction

D. Noise Removal–

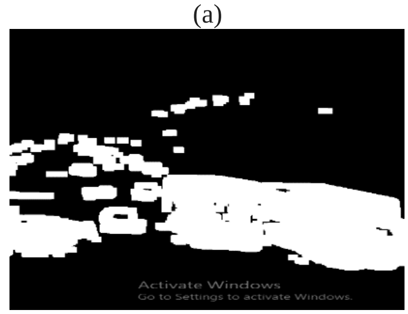
Digital videos are prone to various types of noise. Noise is the result of an error in the image acquisition process that results in pixel values that do not reflect the true intensities of the real scene. Noise can be introduced in the video while acquiring it directly in a digital format, the mechanism for gathering the data such as a CCD detector can introduce noise. We have removed noise present in the video with the help of Morphological Transformation. It needs two inputs, one is our original video, the second one is called a structuring element or kernel which decides the nature of the operation. Equation (9) represents the structuring element used for removing noise. We have used 'w' as the structuring element of size 2*2 and have applied it first to erode the image and then to dilate. Figure 5(a) shows the snapshot after performing erosion operation on the background subtracted image and Figure 5(b) shows the snapshot after performing the dilation operation on the eroded image.

$$w = \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix} \quad (9)$$

The convolution of a filter w(x,y) of size m*n with an image f(x,y) is given by:-

$$w(x,y) * f(x,y) = \sum_{s=-a}^{a} \sum_{t=-b}^{b} w(s,t) f(x-s, y-t) \quad (10)$$

(a)



(b)

Figure 5 (a). Image after erosion (b). Image after dilation

E. Shadow Removal–

For accurately measuring the speed it becomes very important to eliminate the shadow from the video. Since later processing like localization, speed estimation depends on the correctness of object segmentation, that's why it is very important to get rid of shadow. After examining the property of shadow we conclude that shadow regions are darker and have certain fixed pixel value. The approach we have used involve converting colour image to gray level image with the help of equation (11), from gray level image we plotted a histogram shown in Figure 6, by analyzing the histogram we found that gray level 140 was suitable for getting rid of shadow that's why we applied thresholding using equation (12) and to get a binary image without shadow using equation (13). Figure 7(a) shows the colored image with a shadow, Figure 7(b) shows the binary version of the same, Figure 7(c) shows the result of thresholding applied on the gray level image.

$$I_{gray} = 0.216 \times I_{current}(R) + 0.7152 \times I_{current}(G) + 0.0722 \times I_{current}(B) \quad (11)$$

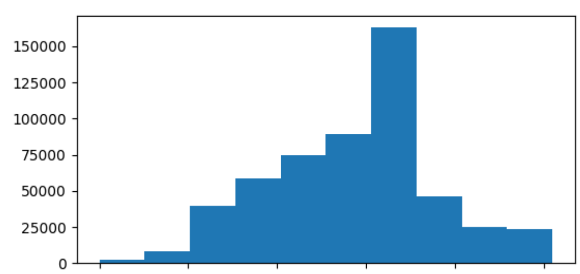
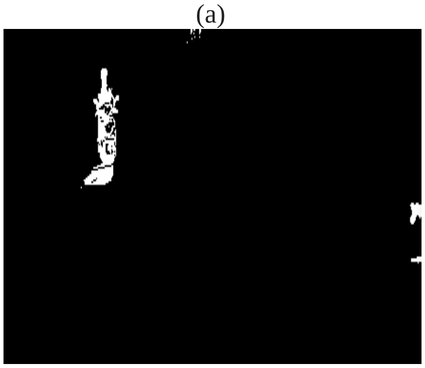


Figure 6. Histogram of the gray level image for shadow removal

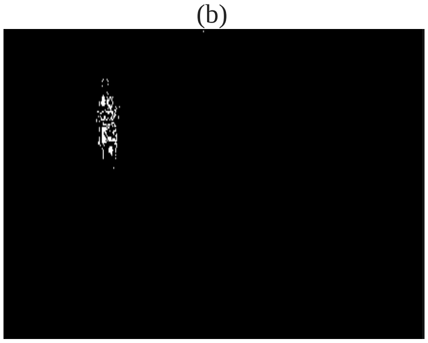
$$I_{Thresholding} = I_{Th} = \begin{cases} 0 \quad ; & \text{if } I_{gray}(x, y) < 140 \\ 255 \; ; & \text{if } I_{gray}(x, y) \geq 140 \end{cases} \quad (12)$$

$$I_{without\ shadow} = I_{Th} \cap I_{bg} \quad (13)$$

(a)



(b)

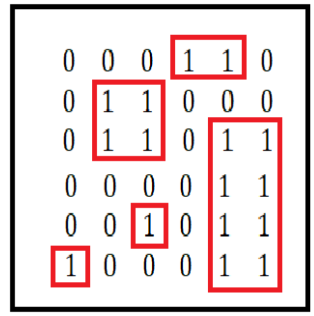


(c)

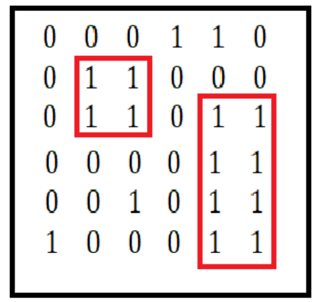
Figure 7(a). Color image (b).Binary image after BS with shadow (c). A binary image without a shadow

F. Localization of Moving Vehicle and Finding Centroid–

Contours of various moving objects present in the video were found out, Figure 8(a) shows various contours that were identified. Each contour is processed individually by finding its (x, y) coordinates along with width (w) and height (h) of moving objects. After analysis a threshold value was set on the width and height of the contour so that we can discard contours whose width and height are below consideration, Figure 8(b) shows the output after thresholding. Remaining contours are inscribed in a rectangular box and their centroid point was calculated with the help of equation (14) and plotted on the video. Figure 8(c) represents the snapshot after the localization of moving vehicles (seen by the blue rectangular box) along with their centroid (seen by the red dot).



(a)



(b)

Figure 8(a). Various contours identified (b).Contour left after thresholding

$$C = \left(x + \frac{w}{2}, y + \frac{h}{2}\right) \quad (14)$$

Here,
x, y = coordinates of boundary points of the object.

Figure 8(c) Image after localization and centroid plotting

G. Creating ROI–

For determining the speed of a vehicle we have to construct an ROI box. Inside this box, we will be performing the actual operation of speed calculation. Figure 9 depicts ROI box construction on lane1(drawn by yellow color), similarly for lane2 and lane3 we can construct these boxes for speed calculation. In our study, we have constructed an ROI box on lane1 only but with the help of superposition, we can apply the same for lane2 and lane3 for speed calculation. Length of the ROI box is chosen in such a way that only one vehicle can inscribe inside it, thus CSCS can correctly perform the speed estimation task for multiple vehicles as well. Thus one has to be careful while choosing the dimensions for the ROI box.

Figure 9. Image after constructing ROI box

H. Speed Estimation–

For speed calculation, we are going to count the number of frames for which the vehicle was inside the ROI box. Frame count will start incrementing as soon as the centroid of the vehicle comes inside ROI box and will stop when the vehicle exits from the ROI box, the status of the vehicle(whether it is inside ROI box or outside) is given by status flag defined by equation(15).

$$\text{Status flag} = \begin{cases} 1 & , if\ C\ inside\ ROI\ box \\ 0 & , if\ C\ outside\ ROI\ box \end{cases} \qquad (15)$$

Finally, we have frame count, length of ROI box, frames per second(FPS) value for the camera used for speed estimation. The formula for speed calculated by using these values is given below

$$S = \frac{\text{Distance} * \text{FPS}}{\text{Frame count}} \qquad (16)$$

Here, Distance = Length of ROI box, Frame count = Number of frames for which the vehicle was inside ROI box, FPS = Frame Per Second of the video.`

Figure 10(a) depicts that vehicle1 is entering in ROI box, while the count value is set to zero because no vehicle has passed through the ROI box, the speed limit is set to 75Kmph, Figure10(b) depicts that vehicle1 is leaving ROI box. As soon as the vehicle1 comes out of the ROI box its speed is updated as 90Kmph and the count value is incremented by one and it was found that the speed was greater then 75Kmph hence it has been labeled by red.

(a)

(b)

Figure 10 (a)Vehicle1 entering ROI box (b)Vehicle1 leaving ROI box

Figure 10(c) depicts that vehicle2 is entering the ROI box, Figure 10(d) depicts that vehicle2 is leaving the ROI box. As soon as the vehicle2 comes out of the ROI box its speed is updated as 70Kmph and the count value is incremented by one since speed was found less then 75Kmph hence it has been labeled by black.

(c)

(d)

Figure 10 (c). Vehicle2 entering ROI box (d). Vehicle2 leaving ROI box

I. DataBase Creation–

Data produced from the algorithm can be stored in a log file for tracking the number of vehicles that are breaking the speed limit along with time and the geographical location. Table 1 depicts sample data generated from the algorithm.

Table 1. Sample data generated after processing the video

SPEED LIMIT =75 Kmph

S.NO	SPEED	TIME	LOCATION	SPEED LIMIT CROSSED?
1	90	10:14:51	Nagpur 1	Yes
2	70	11:15:09	Nagpur 2	No
3	70	11:15:24	Nagpur 1	No
4	77	12:02:19	Nagpur 3	Yes
5	80	12:02:40	Nagpur 4	Yes
6	55	12:40:30	Nagpur 5	No

III. Experiment and Result

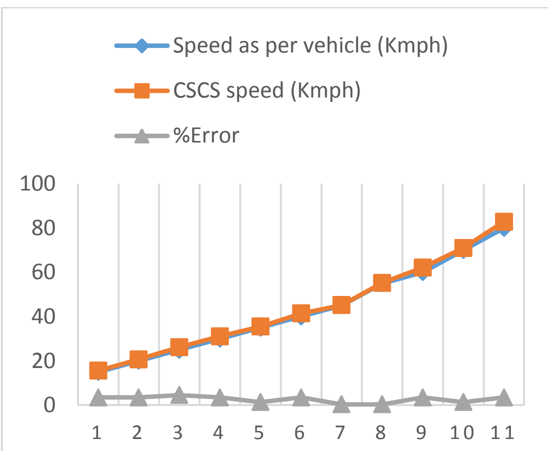
CSCS was tested for various speeds of the vehicle. Figure 11(a) and 11(b) depicts some of them. It was found that the speed was estimated with a accuracy of 95.44%-99.64%. Table 2 shows sample speed measured from CSCS. The camera used in the study has a frame rate of 30fps. A frame is captured at every 33.3ms, the pixel size of the camera is 1.12 um. Aperture and the focal length is f/1.7, 27.22mm. The length of the ROI box was calculated to be 4.60meter. CSCS was found to achieve satisfactory performance. CSCS accuracy will increase with an increase in camera's fps count. CSCS can be further integrated with the ANPR system to get the characters from the license plate of overspeeding vehicles and further action can be taken by the respective authority.

Figure 11 (a). Speed estimation when vehicle speed was 15Kmph

Figure 11(b).Speed estimation when vehicle speed was 55Kmph

Table 2. A sample of speed measurements with CSCS

Trials	Speed as per vehicle (Kmph)	CSCS speed (Kmph)	%Error
1	15	15.52	3.47
2	20	20.7	3.5
3	25	26.14	4.56
4	30	31.05	3.5
5	35	35.48	1.37
6	40	41.4	3.5
7	45	45.16	0.36
8	55	55.2	0.36
9	60	62.1	3.5
10	70	70.97	1.39
11	80	82.8	3.5



Graph 1. Graph of speeds and error rate with CSCS.

IV. Conclusion

CSCS provides a number of benefits:

- CSCS is cheap as compared to a traditional radar system.
- CSCS can perform speed estimation task for multiple vehicles simultaneously.
- CSCS is better than some other digital image processing algorithms when compared in terms of processing power, complexity, cost, efficiency, features (geographical location).
- CSCS is an automated system so it reduces manpower.

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