Speed Detection using Image Processing

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Abstract— **With the increase in automobile use, the highway traffic have only surged. At the current rate of increasing automobiles, speed determination has become a major concern in avoiding fatal accidents. Radar technology is the current productive way used for speed detection. In this paper we have come up with an alternative method of using image and video processing which can overcome the drawbacks of radar guns. It uses the live video stream from the surveillance cameras for calculating the speed of the vehicle. The speed of vehicle is updated every half a second, hence keeping a track on acceleration and deceleration of vehicle in the field of view of the camera. Any violation in the speed laws can be observed and notified to the officer of law. This helps in keeping track of the speed violators and saves the effort of an officer holding a radar gun on the highways. The video can also be saved for future use. The speed calculated shows an error of only 3% in real time and is tested in many experiments. It has proven to have achieved a satisfactory performance.**

Keywords— Speed Detection; Vehicle Detection; Adaptive Background Subtraction; Shadow removal component

I. Introduction

Highway traffic control has been a challenging conundrum for the government on a global scale. According to reports, a total of around 1.3 million crashes happen all over the world each year; a majority of them caused by over speeding of vehicles on highways. It will be impossible to provide sufficient manual labor to control traffic at all the busy areas if the on-road vehicles keep increasing at the current rate. Using radar technology for speed detection is not enough and the current scenario demands a better alternative [10]. Radar guns run on the Doppler shift phenomenon; radio waves are incident on the object of which speed is to be determined and the frequency of the reflected radio waves varies depending on the rate at which the object is moving. This change in frequency of reflected waves can be used to calculate the speed of object. Though radar technology is found to be giving promising results, several drawbacks exist in this technology [7] as mentioned below.

- Speed of only one object can be found at an instance.
- While in use, if there are any devices that generate radio waves in the near vicinity, the results are influenced.
- Extremely expensive.
- Radar gun must be pointed towards the direct path of the incoming traffic.

All these drove the researchers to look for an alternative that is better in terms of both performance and cost. Image and video processing has proven to give more reliable results with lesser costs and efforts. Image processing is being used from the past decade for Vehicle speed detection, categorization, counting and many more. This paper illustrates how we can use mere CCTV cameras on highways to detect the speed of vehicles. The prototype developed is designed using MATLAB software and can process on core2duo processor with 2Ghz.

The following are the steps involved in the speed detection of vehicles.

First phase is Object Detection – Several background and foreground extraction algorithms exist, like the use of Gaussian distribution by Bailo et al.(2005), adaptive median by Shi et al. (2002), morphological background estimation by Assad and Syed(2009) etc., but keeping in view the complexity and reliability, adaptive background subtraction is used where the background is separated from the foreground (vehicles). Second phase is object tracking which involves shadow removal, convex hull, morphological operations, plotting a bounding box around the objects detected, finding its centroid and keeping track of the objects in each frame of the video. Third comes the phase for the speed calculation in which the final speed in km/hr is calculated. Fully functional algorithm is developed and the results are shown in Section III.

Paper is organized as follows. Section II deals with the system design and implementation. Section III presents the results in each phase mentioned above and section IV concludes the paper.

II. SYSTEM DESIGN AND IMPLEMENTATION

This section discusses the system design and implementation and can be further divided into three successive sections as listen below

Vehicle Detection
Vehicle Tracking
Speed Calculation

Detailed overview of the process with a flowchart is shown in figure 1.

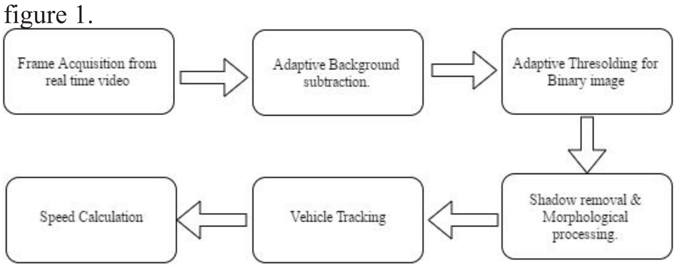

Fig. 1. Flowchart for speed detection.

A. Vehicle Detection

Object detection is a well-known research and a lot of algorithms are proposed on the same[1] . But vehicle detection in real time video is a challenging task. Any false detection can result in a false alarm.

(1)Background subtraction

Background subtraction is the core idea for a number of object detection algorithms. In Normal background subtraction a fixed image called background image is used. Every frame of the video is then subtracted from this background image and the resulting image is then subjected to the thresholding process to get the final output as a logical (binary) image. This can be mathematically represented as Eq. 1

$$if \mid B(x,y) - f(x,y) \mid \geq Th \; then \; F(x,y) = 1$$
$$0 \; otherwise \qquad (1)$$

Here,
$B(x,y)$ is the corresponding pixel intensity value at (x,y) co-ordinate,
$f(x,y)$ is the current frame pixel value at (x,y) and
$F(x,y)$ is the resulting binary image pixel value at (x,y) .

Native background subtraction has its own drawbacks. If any stationary object that has been present for a long time in the background image moves out of the frame, it leaves a hole behind. And since the background image is fixed, any changes in the intensity of light will also be detected as false objects. It is not feasible to update the background image for each illumination change. Hence a new self-adapting method called Adaptive background subtraction method is used.

(2) Adaptive Background subtraction

Adaptive Background subtraction is similar to the native background subtraction method except for the fact that the background image keeps updating itself in case of any changes by the Eq. 2

$$new\_bk\_img = p \cdot old\_bk\_img + (1 - p) f \qquad (2)$$

Here, new_bk_img is the updated background image old_bk_img is the background image for previous frame processing and f is the current frame.

p is a constant usually close to 0.95. In simple terms it can be explained in this way: the new background image is 95% of old background image, added to 5% of current frame. This 5% helps in updating the background image in case of any illumination change.

Since the background image keeps updating, the corresponding thresholding value should also be adaptable. At the darker time of day(night) the threshold value should be low and at brighter time(midafternoon), it should high. Hence the Threshold value is given by Eq. 3

$$new\_thresold = a \cdot avg + b \qquad (3)$$

Here avg is the Average ambient Intensity. To calculate this, 20 evenly spaced different pixel intensity values are considered. First the image is divided to 10 evenly spaced rows and columns .Pixels close to the point of intersections is considered for the calculation of Average ambient intensity [9]. The constants a,b values are determined by a series of experiments to be 0.63 and 8 respectively.

B. Vehicle Tracking

Tracking the objects detected frame by frame is a challenging task as the system won't be able to extract cohesive temporal information about the object. At the same time inaccurate foreground detection due to shadows & noise makes the tracking more difficult.

Vehicle tracking here is further divided into categories

Object segmentation
Object labeling, bounding box & center extraction

(1)Object segmentation

Object segmentation deals with the connectivity of the objects. In other words, we must ensure that all the objects are connected as one part. Otherwise, the processing that follows, results in making a single object into multiple objects. First shadow removal is done followed by some morphological operations.

Shadow removal:

As adaptive background subtraction handles any illumination changes, we also need to remove the shadows in order to avoid false detections using the following properties of a shadow:

1. Shadow regions are usually darker.

2. Shadows represent the same background pixel under darker illumination.
3. They share the same background texture pattern.

Edge detection can be the obvious approach but we use a simpler method of comparing the pixel values in current frame and the background pixel, which has proven applicable to a wide range of shadows. After several experiments it can be concluded that if $0.25 \leq f(x, y) / B(x, y) \leq 0.93$ then that pixel can be considered as shadow and made to 0, i.e., background [4].

Morphological operations:

Convex hull is the first of the several morphological operations performed on the binary image post shadow removal. In convex hull, any two white pixels within the object are connected with a line and all the points on the line are made white. This can be called as a hole filling method and helps convert almost all connected objects to blobs. In a similar manner, few operations like erosion, dilation, closing, opening and hole filling morphological operations are performed and the final result of the image with vehicles as proper blobs is achieved with all the noise removed [8] [9].

(2)Object labeling,bounding box and center extraction

Next step is to keep a track of the objects detected. Each vehicle (object) detected is assigned with a unique label and from the moment the object enters the scene till it leaves the scene its unique label is preserved. Bounding box is then plotted around each object and the center of the box is calculated and stored in an array as centroid of the object. These centroids serves as the reference point for the location of an object and help us in speed calculation.

C. Speed Detection

In this final phase the speed of the blobs detected is calculated and shown on screen. This phase can be further subdivided into

Calibration factor and
Speed calculation

(1)Calibration factor

Camera calibration is an important aspect of speed calculation. It is the real-world distance to pixel ratio. The images captured by the camera are in 2-D (Dimensions) but in real world it is 3-D (Dimensions). However the vehicle can't move above the ground surface (fly into air) so it can be considered as 2D to 2D conversion [7]. Calibration factor can be calculated by knowing the actual length of any object and dividing it by length in pixels of the same object in image. In figure 2 a cross sectional view of the camera, its field of view and the road.

$$c = \frac{\text{length of the object in real world(cms)}}{\text{length of the object in frame(pixels)}}$$

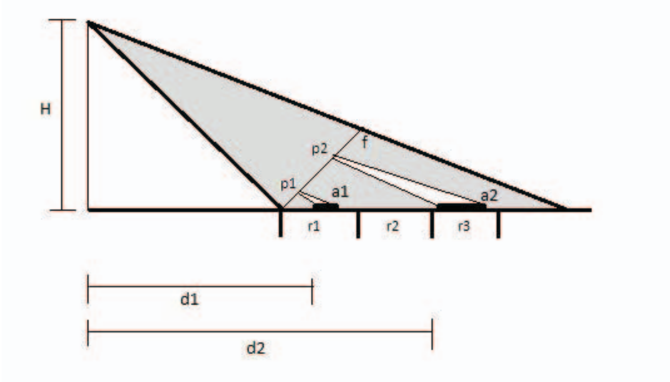

Fig 2 . Cross sectional view of the camera and its field of view.

Here the camera is placed at a height H from the surface and the field of view is shaded grey in colour .Consider f to be the frame on to which the road is captured in pixels. Consider a pixel p1 on the image f which captures a small region of area a1 at a perpendicular distance d1 from the camera. Now consider another pixel p2 which captures area a2 at a distance d2 from the camera. From the figure it can be easily seen that a2>a1, i.e., as we move away from the foot of camera in the field of view, greater area (hence length) is covered in a single pixel thereby making the calibration factor not constant. Though the change is this factor is small and negligible in smaller regions, this change can't be ignored as we move to far away regions. Hence to solve this issue we divide the road surface in to segments r1, r2, r3 etc., as shown in figure and calibration factor is calculated for each segment. Only 2/3 of the image is considered for vehicle detection and speed calculation. Hence the segments can be limited to 4-6 segments and proper accuracy in calibration factor can be obtained.

(2)Speed Calculation

The final speed in km/hr is calculated now and the result is shown. The speed is updated at every 0.5sec, assuming the video is at 30 frames per second; the centroid values stored in an array of every 15th frame is considered. Now the distance covered by each object can be calculated from the Eq. 4

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

Here,
(a, b) is the coordinates of the centroid of an object in i-th image
(e, f) is the centroid coordinates of the same object in i-15th image.
Time taken for these 15 frames can be calculated from frame rate.
The final speed is given by Eq. 5

$$v = c \cdot d / T \tag{5}$$

Here C is the calibration factor in that respective region in km/pixel
D is the distance travelled by object in pixels
T is the time for 15 frames in hours.

III. RESULTS

Here we explain our accomplished results step by step with figures. Figure 3 shows frame number 80 from the video used. First step being adaptive background subtraction, the current frame is subtracted from the updated background image formed in previous (79^{th}) iteration shown in figure 4.The resulting image, after thresolding is shown in figure 5.a. As discussed earlier, only $2/3^{rd}$ of the frame is considered and the rest of the objects detected are ignored. The figure 5.b illustrates this.

In the next phase, i.e., vehicle tracking, as a part of object segmentation shadow removal is done and the result obtained is figure 6. As part of morphological operations, first convex hull algorithm is applied and it can be seen from the result, figure 7 that convex hull connects most of the holes. Some objects can be seen as two objects but are close enough. Such parts are connected as one object after applying more morphological operations and final binary image is shown in figure 8. Now, as a part of the last stage of vehicle tracking, bounding box is plotted for objects detected and centroid is determined, figure 9. The final phase is the speed detection. Calculations are made and the speed in plotted onto image and the final output image is shown in figure 10.

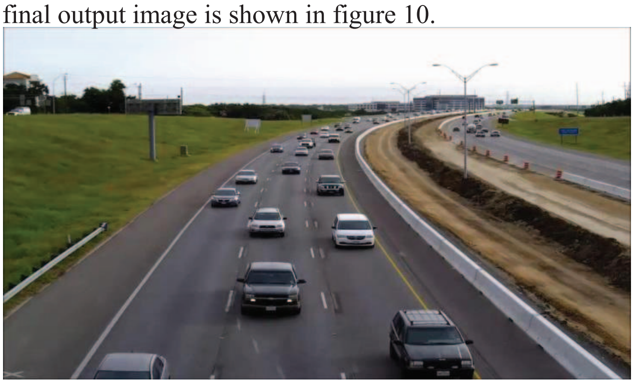

Fig 3 . A sample scene with multiple objects.

Fig 4 . Adaptive background image

Fig 5.a . Resulting binary image after thresolding

Fig 5.b . Only considering $2/3^{rd}$ image.

Fig 6 . Shadow removal

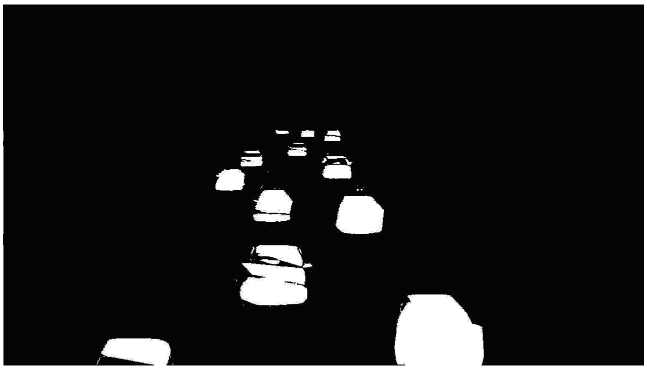

Fig 7 . Convex hull algorithm

Fig 8 . Resulting binary image after morphological operations

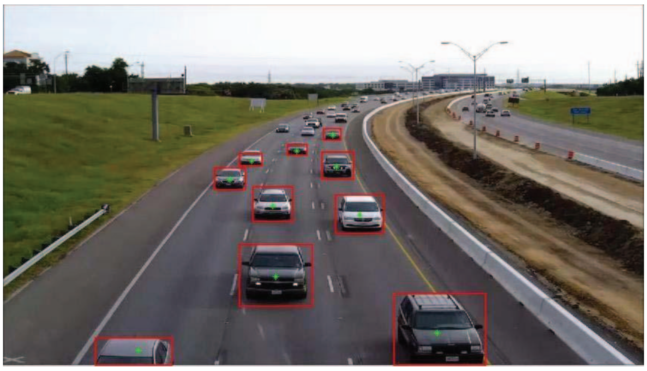

Fig 9 . Centroid and bounding box

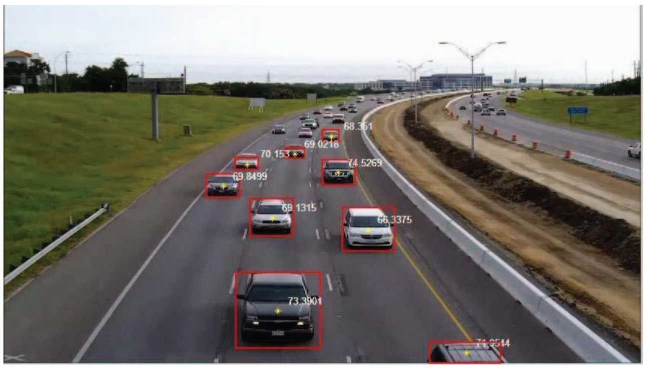

Fig 10 . Speed detection

The above results illustrate the success in achieving the speed detection of the vehicles. The challenges faced are making the proposed method work at different times of the day. The proposed adaptive background subtraction method is tested and found to be working well even at night time and under hazy situations. The speed detected is updated every half a second and hence is useful to keep track of any speed changes. Compared to traditional radar systems, proposed speed detection method is found to be accurate and more reliable. If the radar gun is located on the side or above the road then cosine errors increases. 15^0 shift in Radar gun from direct path results in 3% deviation of measured speed from actual speed of vehicle, if deviation is 30^0 than the error in measured speed from actual speed is 13%. The proposed method is seen to have a maximum error of 3% in detected speed.

IV. Conclusion and future work

Digital image processing has shown promising results in object detection and speed calculation. The results shown above are consistent with the fact. It is immune to weather and illumination changes. The shadow removal method used is a simple and time saving compared to any previous approaches.

Further the study can be expanded to make it work under foggy situations. It can also be expanded to various fields of security measures. Speed violators can be noted. Using text recognition, number plates of the over speeding vehicles can also be captured. Besides the working advantages, this is a cheaper alternative over the traditional radar system. With a very high frame rate camera, this work can also accommodate objects moving at very high speed.

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