To assess the accuracy and reliability of the vehicle speeds obtained from fixed mounted cameras

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Abstract

Estimation of vehicle speeds from road surveillance cameras is popular in the field of road traffic management and crash investigation. Estimation of the travel speed of a vehicle involved in an accident will be helpful for determining speeding related issues for research and legal purposes. This paper assesses the accuracy of the vehicle speeds estimated from the video footages of any fix mounted camera. The principle used to estimate vehicle speed is the basic speed-distance-time relationship. This method is rapid and reliable to obtain an estimate of speed range using Closed – Circuit Television (CCTV) camera irrespective of the vehicle body type, camera position and orientation angle. The results indicate that the vehicle speed output obtained shows a tolerance range of +/- 3 kmph and percentage error ranging in-between 3% to 7% for various range of speeds. Percentage error is high for low speeds and vice versa.

Introduction

This paper focuses on assessing the tolerance range for the speeds obtained from CCTV footage. This research is a small step to estimate the average travel speed of accident vehicles using CCTV cameras and validate the results obtained. This methodology will be useful for developing countries to use their existing facilities.

In developed countries, speed of the vehicles are calculated by the camera itself by the image processing technique [1] RADAR (Radio Detection and Ranging), LIDAR (Light Detection and Ranging) devices and SDCS (Speed Detection Camera System) [2], to do the survey on the speed of different types of vehicle for particular region or road. These methods provide the speeds with good accuracy.

If an accident is captured by a surveillance CCTV camera of any government or private agency, these cameras do not have the facility to calculate vehicle speeds automatically. By using these CCTV footages, vehicle speeds can be calculated for the purpose of accident research. To check and validate this process, we performed some practical tests and the results are published in this paper.

The formula used to calculate the vehicle speed is the basic speed-distance-time relationship.

\[ \text{speed (m/s)} = \frac{\text{distance (m)}}{\text{time (s)}} \]  

Methodology

Methodology includes determination of distance and time with the help of CCTV footage. The values extracted from the CCTV footage can be used in the equation (a) to obtain the speed.

The distance of the displacement from point A to point B within a video can be considered in calculating the speed (e.g. distance between two or more known points in the scene such as white lane line distance etc.)

However the video is a collection of images/frames played back to back to create an illusion of continuous motion. Time is calculated based on the number of frames recorded to travel a defined distance. Some media players even have the facility to show the time in milliseconds for the particular frame. Time can be determined by calculating the time difference between the start and end frames.

If there are no particular points/objects available on the road to calculate the reference distance, or if the road marking is not available to calculate the distance then in
such cases the target vehicle's wheelbase can be considered as a reference distance.

To estimate the vehicle speed from the CCTV camera, the following test procedures were conducted at two different locations with different camera configuration and camera location (with respect to vehicle travel direction).

First test was performed as primary test to check whether video / CCTV footages can be used to calculate vehicle speeds or not. Second test was performed with an aim to validate the primary test results by mounting an actual CCTV camera instead of mobile phone camera.

Theoretically we have to place the speed gun along the line of the vehicle velocity vector. But practically it was not possible to place. So, speed gun was placed little offset to the vehicle travel direction to calculate the speed and the angle between speed gun and vehicle travelling direction was kept minimum to minimize the cosine effect.

We have seen that there is a difference in the speedometer and the speed gun reading. Considering the fact that speed guns are more accurate in comparison with speedometer, we have used the speed gun reading to calculate the percentage error for the speeds calculated using CCTV footage.

The percentage error was found from the below mentioned formula,

\[
\text{Percentage error} = \frac{\text{ABS} (\text{Speed gun reading} - \text{Calculated speed})}{\text{Speed gun reading}} \times 100
\]

“ABS” indicates absolute value.

Details of the instruments used in the tests are provided in the Table 5 in Appendix.

**Primary test**

Figure 1 shows the location of the test performed.

![Figure 1](image1.png)

Test vehicle was driven on the test track, the vehicle direction is shown in Figure 1. Two digital cameras and one smart phone camera were used to record the vehicle movement. A hand held speed gun was positioned between camera 2 and 3.

![Figure 2](image2.png)

Figure 2 shows test track image with relative position of camera 1, camera 2 and speed gun.

For each iteration the test vehicle was driven at a constant known speed on the test track. Speedometer reading was constantly monitored by the driver and a team member who was seated at the co-passenger seat. All three cameras were capturing the movement of the vehicle from different angles. Test vehicle speed was constantly monitored by a speed gun as well.

Figure 3, 4 and 5 represent the orientation of the cameras 1, 2 and 3 respectively with respect to the travel direction of the vehicle.

![Figure 3](image3.png)
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Secondary test
Figure 6 shows the location of secondary test and the relative positions of the cameras and the speed gun placed on the test site.

The CCTV camera was placed at a height of 5 m from the ground to reproduce a real world scenario. Two digital cameras were also used to check the accuracy of the results obtained from the CCTV camera.

Figure 7 shows the test site and location of the fix mounted CCTV camera.

Figures 8, 9 and 10 are images captured by camera 1, camera 2 and CCTV camera respectively representing the orientation with respect to the travel direction of the vehicle.

Test vehicle was driven at the constant known speed and its speed was also monitored by a hand held speed gun. Two cameras and one CCTV camera were capturing the movement of the test vehicles. The results of primary test and secondary test are presented in the results section of this paper.

Methodology for calculation of vehicle speeds from video footages:
Follow the below mentioned steps to calculate speed of the vehicle from CCTV footage,
1. CCTV systems in general are provided with an associated playback software (default player) to record and playback the footage. We recommend the usage of the raw CCTV footage and the default player for the purpose of speed calculation.

2. Identify the Frames Per Second (FPS) of the original CCTV footage. This can either be identified by checking the video properties of the footage or by manually counting the number of frames recorded per second.

3. Here we have used the wheelbase of the test vehicle as the reference distance.

4. Pause the video footage to mark/select the contact point of the front tyre and road surface (Point A) as shown in Figure 11.

5. Play the footage frame by frame until the rear tyre is at point A as shown in Figure 12.

6. Find the number of frames taken by the test vehicle to travel the distance equivalent to its wheelbase. (Number of frames will be counted while executing point no. 5)

7. The number of frames taken to cover the wheelbase distance is not always a whole number, hence an approximation is made by scaling the positions of rear wheel in the last and the second last frame with respect to the reference point.

8. Find the time taken to travel the wheelbase (WB) distance from the below formula.
   - Time to travel the WB distance = \( t \)

9. Use the wheelbase value of the test vehicle provided by the manufacturer.

10. Calculate the average speed of the vehicle from the below formula,
   - Average speed of vehicle = \( v \)

\[ v = \frac{Distance\ (Wheelbase\ of\ vehicle\ (m))}{time\ (s)} \]  
\[ ...(2) \]

- Substituting equation (1) in equation (2)

\[ v = \frac{Distance\ (Wheelbase\ of\ vehicle) \times FPS\ of\ video}{Number\ of\ frames\ to\ travel\ the\ distance} \]  
\[ ...\ (3) \]

The operating software we have used to calculate vehicle speeds is VLC Media player.

The steps followed to calculate the average speed were:

1. The CCTV footage was played using VLC media player.

2. FPS of the video footage was found using the below mentioned path,
   - Tools > Codec Information (Shortcut: CTRL + J)
   - A dialogue box as shown in Figure 13 will pop up where the FPS information was provided.

3. The video was paused and the contact point of front tyre was road surface (Reference point) was marked.

4. Using the frame by frame option, the number of frames were counted for the rear tyre to pass over the reference point. The
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distance travelled by the vehicle is equivalent to the wheelbase.
5. VLC media player allows the user to play video frame by frame using the following tool shown below
   • Frame by frame option: 
   • Key board shortcut for this option is ‘E’ for VLC media player.
6. The wheelbase measurement of the vehicle was considered as per the manufacturer specifications.
7. The speeds were calculated using the equation (3) shown above.

For example, number of frames to travel wheelbase distance = 8 frames
Frame rate of the video = 25 FPS
Wheelbase of the vehicle = 2.57 m

\[ v = \frac{2.57 \times 25}{8} \]
\[ v = 8 \text{ m/s} \]
\[ v = 29 \text{ kmph (kilometre per hour)} \]

**Results**
The vehicle speeds calculated from the footage recorded using the various cameras are tabulated below.

- **Primary test**
  During the primary test, car (Maruti Suzuki Ertiga ZDi) and motorcycle (KTM Duke 390) (Indian model) were used as the test vehicles.

Seven test iterations were performed using the car (Maruti Suzuki Ertiga ZDi) and their results are shown in Table 1.

<table>
<thead>
<tr>
<th>Test No</th>
<th>Speedometer</th>
<th>Speed gun</th>
<th>CCTV</th>
<th>Camera – 1 (% error)</th>
<th>Camera – 2 (% error)</th>
<th>Camera – 3 (% error)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>31 (3%)</td>
<td>31 (3%)</td>
<td>30 (0%)</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>31 (3%)</td>
<td>31 (3%)</td>
<td>30 (0%)</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>31 (3%)</td>
<td>31 (3%)</td>
<td>30 (0%)</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>38</td>
<td>38</td>
<td>37 (3%)</td>
<td>37 (3%)</td>
<td>37 (3%)</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>47</td>
<td>47</td>
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<td>49 (4%)</td>
<td>49 (4%)</td>
</tr>
<tr>
<td>6</td>
<td>50</td>
<td>48</td>
<td>48</td>
<td>49 (4%)</td>
<td>49 (4%)</td>
<td>49 (4%)</td>
</tr>
</tbody>
</table>

Three test iterations were performed with the motorcycle (KTM Duke 390) and their results are shown in the Table 2.

<table>
<thead>
<tr>
<th>Test No</th>
<th>Speedometer</th>
<th>Speed gun</th>
<th>CCTV</th>
<th>Camera – 1 (% error)</th>
<th>Camera – 2 (% error)</th>
<th>Camera – 3 (% error)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>29</td>
<td>30</td>
<td>30 (3%)</td>
<td>30 (3%)</td>
<td>30 (3%)</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30 (0%)</td>
<td>30 (0%)</td>
<td>30 (0%)</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
<td>48</td>
<td>48</td>
<td>49 (2%)</td>
<td>49 (2%)</td>
<td>49 (2%)</td>
</tr>
<tr>
<td>4</td>
<td>50</td>
<td>48</td>
<td>48</td>
<td>49 (2%)</td>
<td>49 (2%)</td>
<td>49 (2%)</td>
</tr>
</tbody>
</table>

**Discussion**

As per the test results, it is observed that the percentage error at lower speeds is higher while the percentage error is lower at higher speed.

The accuracy of the speed obtained with this method increases with the increase in FPS. However, the accuracy decreases for a vehicle captured at very high speed by low FPS camera.
The following are the limitations found while using this method,

- CCTV video configuration should be more than 20 FPS to have better accuracy.
- Vehicle must be travelling in the straight path on a straight road.
- Speeds cannot be estimated for vehicles undergoing significant acceleration/deceleration. (Minor acceleration and deceleration will not result in a significant difference in the speed values for small distances).
- Speeds cannot be calculated for a vehicle if the camera was capturing the video while in rotational motion. The camera angle and view has to be fixed.
- This method cannot be used for footage having variable frame rate.

**Conclusion**

The tests results indicate that the speeds estimated from cameras with FPS range of 25 to 30 are within a tolerance range of +/-3 kmph or 7% error irrespective of the vehicle body type, camera position and orientation angle.

**References**


**Acknowledgement**

We sincerely thank our management for providing us a vehicle and equipment to perform these tests and we also thank the team who helped us during the tests and provided their vehicles to perform various tests.

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**Table 5**

<table>
<thead>
<tr>
<th>Instrument name</th>
<th>Instrument detail</th>
<th>Other detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camera 1</td>
<td>Nikon COOLPIX P610 (Point and shoot digital camera)</td>
<td>30 FPS</td>
</tr>
<tr>
<td>Camera 2</td>
<td>Nikon COOLPIX P520 (Point and shoot digital camera)</td>
<td>25 FPS</td>
</tr>
<tr>
<td>Camera 3</td>
<td>Samsung Galaxy E7 mobile phone</td>
<td>30 FPS</td>
</tr>
<tr>
<td>CCTV camera</td>
<td>Secureye S40-W650IR</td>
<td>25 FPS</td>
</tr>
<tr>
<td>Speed Gun</td>
<td>Bushnell Velocity Speed Gun</td>
<td>+/- 2 kmph accuracy</td>
</tr>
</tbody>
</table>
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Photos of Camera 1, 2, 3, CCTV camera and Speed Gun are shown in Figures 14 to 18 respectively.

![Figure 14](image1.png)  ![Figure 15](image2.png)  ![Figure 16](image3.png)  ![Figure 17](image4.png)  ![Figure 18](image5.png)

The details of vehicles used in the tests are as below,

<table>
<thead>
<tr>
<th>Vehicles Used</th>
<th>Model Year</th>
<th>Wheelbase (metre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maruti Suzuki Ertiga VDi</td>
<td>2015</td>
<td>2.74</td>
</tr>
<tr>
<td>Maruti Suzuki Alto K10 VXi</td>
<td>2010</td>
<td>2.36</td>
</tr>
<tr>
<td>KTM Duke 390</td>
<td>2013</td>
<td>1.367</td>
</tr>
</tbody>
</table>