A Video-based Method for Evaluating Traffic Data from Detectors

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Abstract:

This paper presents a video-based method for evaluating and validating volume and speed data collected with traffic detectors. Assessing the detector data reliability is a critical task for all Intelligent Transportation Systems (ITS). Their performance will be significantly impacted by the data quality. Most existing studies mainly use volume as the only variable for evaluating the detector quality. A cost-efficient and rigorous method that can concurrently evaluate both volume and speed from the detectors is not available yet.

The video-based method presented in this study is both cost-efficient and sufficiently reliable for evaluating detector data for ITS system operations. For example, the performance of a travel time prediction system is very sensitive to the quality of the detector data. This paper will mainly detail the key features of the proposed system and its application in a case study of RTMS detector data on I-70 corridor in Maryland.

Background:

With the fast developments of Intelligent Transportation Systems (ITS), traffic detectors that provide traffic count, speed and occupancy have become increasingly popular. Regardless of the employed technologies, most detectors need to have their internal parameters calibrated property. Hence, how to efficiently and effectively evaluate the functioning of available traffic sensors has emerged as one of the essential tasks in the traffic control, especially in view of providing the real-time operational data. In review of related literature, it is noticeable variety of methods for detector data evaluation exist (1). Most of those focus mainly on volume count. A reliable and efficient method for concurrently evaluating the volume and speed data still remains to be developed.

Video-based methods have been widely used in the fields of the vehicle detection and the movement tracking (2, 3, 4). However, the speed measurement using video-based method has been found to be unreliable with traditional analog video capturing devices for short travel distances in the literature. Kuo and Machemehl (5) analyzed the probability of measurement errors and their relations with video frame rate and measurement distance, and found the speed trap distance needs to be at least 15 meters long for one of the scenarios. Bonneson (6) enlarged this distance to 20 meters after further analysis on the potential bias and errors. With such a long required distance, video-based method has been found to be not suitable for measuring speed in a segment where vehicles change speed frequently.

With the development of high quality digital video capture devices, the image quality has been significantly improved. At the same video recording frame rate of about 30 fps, the digital devices provide higher resolution (720 by 480) and sharper edges of the objects in the video, which is one of the main concerns that contribute to measurement errors. Therefore, the analysis results in the previous literature that are based on traditional analog devices do not hold for the new devices. Furthermore, computer technologies have been playing more and more important roles in helping to improve the data measurement. This paper takes consideration of the abilities of new digital video capturing systems and evaluates their performance on the video-based speed measurement with the help of a developed video-processing program. The proposed video-based method is cost-efficient and reliable for validating the speed data from detectors for all ranges of speed. The potential errors have been carefully analyzed in this study, followed by a case study on I-70 corridor in Maryland.

System Features and Operational Procedures

System Components

The developed video-based evaluation system includes the following components:

- One MiniDV camcorder with the ability to record videos with the resolution of 720x480 pixels per frame and the recording rate of 29.97 frames per second with its 20x optical zoom lens;
- One heavy duty tripod, which is 72 inches high, to place the camcorder on the road side stably;
- Highlight spray to mark the parallel reference lines on the road side;
- A GPS receiver that is able to display time acquired from the satellites;
- A developed video-processing program with the ability to high light and extend reference lines and record timestamps when individual vehicle passes each reference line.

Field Survey Procedures

Step 1: Pre-survey preparation:

a) Select an optimal location of the camcorder considering the geometry constraints;
b) Mark the parallel reference lines on the roadside;
c) Measure the distance between parallel reference lines;
d) Check the time difference between the detector and the GPS satellites;

Step 2: Video recording

a) Adjust the zoom of the camcorder to make sure the survey segment occupies almost the entire screen
b) Start video recording and then place a GPS receiver with 3D fix status to show the time acquired from the satellite in front the camcorder for few seconds.
c) Try to avoid the vibration when recording the video
d) Record the GPS time every time a new recording starts after change of battery or tapes.

Step 3: Download the traffic data from the detector and then update the timestamps based on the time difference collected on step 1.d

Data Processing Procedures

Step 1: Capture the un-compressed video by using an IEEE1394 firewire card with video-editing software.

Step 2: Load the video in the developed software

Step 3: Sync the video time with the time on the GPS receiver shown at the beginning of the video

Step 4: Use the software function to highlight and extend the reference lines in the video to cross the road segment

Step 5: Use function keys to record the timestamps of individual vehicle passing each extended reference lines on the screen.

Analysis of System Reliability

Concept of the System

The concept of the system is to compute the average speed v at which one vehicle passes a segment by dividing the length of the segment L with the travel time t.

$$v = \frac{L}{t}$$

With the consideration of measurement errors, the computed speed v' can then be expressed as:

$$v' = \frac{L'}{t'} = \frac{L + \varepsilon_l}{t + \varepsilon_t}$$

Where L' is the measured distance and t' is the measured travel time. ε_l represents the measurement error of distance and ε_t represents the measurement error of travel time.

Measurement Error of Travel Time

With the developed video-processing software, the location of individual vehicle can be traced every $1/29.97$ seconds at the frame rate of 29.97fps. When one vehicle is traveling at 65mph, the travel distance between two adjacent frames is 3.18 feet. Therefore, it is very frequently seen in the video that one vehicle's front wheel is before or after the reference line in two adjacent video frames. In order to estimate the time spot when vehicle actually steps on the line, the following rules were developed:

Distance from vehicle's front wheels to the reference line refers to the distance from the spot at which vehicle's visible front wheel touches the ground to the reference line along the direction of the road. If one vehicle's front wheels are before the reference line at frame n and after the reference line at frame n+1, then the timestamp t' is determined as follows:

$$t' = \begin{cases} t_n & \text{, when } |s_n| \le |s_{n+1}|/2 \\ t_{n+1} & \text{, when } |s_{n+1}| \le s_n/2 \\ (t_n + t_{n+1})/2 & \text{, otherwise} \end{cases}$$

Where t_n is the timestamp of frame n and s_n is the distance from vehicle's visible front wheel to the reference line at frame n.

$$t_{n+1} - t_n = \frac{1}{29.97} \text{ seconds}$$

$$s_n \cdot s_{n+1} \leq 0$$

Based on the experience, mistakes may be made when

$$\frac{1}{5} \leq \left|\frac{s_n}{s_{n+1}}\right| \leq \frac{1}{2} \text{ or } \frac{1}{5} \leq \left|\frac{s_{n+1}}{s_n}\right| \leq \frac{1}{2}$$

With consideration of possible errors at both reference lines,

$$|\varepsilon_t| \leq \frac{1}{29.97} \times \frac{2}{3} \approx 0.0222 \text{ seconds}$$

Measurement Error of Distance

As illustrated in Figure 1, two parallel 2-inch-wide reference lines with approximate lengths of l_R are marked on the road side. The distance between two marked reference lines is measured as L_M. The distance between two extended reference lines in lane i is L_{Ti}. The following issues may impact the computation results:

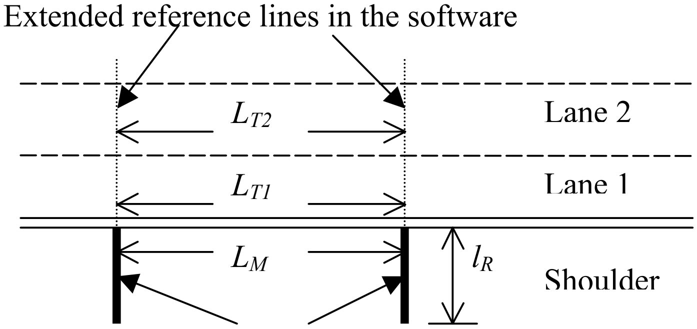

Figure 1. Illustration of the survey site

- ε_M, the measurement error of L_M
- ε_A, the difference between L_{Ti} and L_M

$$\varepsilon_L = \varepsilon_M + \varepsilon_A$$

ε_A is caused by the angel variation when extending the marked reference lines in the software. The possible variation of angle is determined by the width and the length of actual marked reference lines. When the reference lines are both 2-inch wide and 12 feet long, the maximum error can then be calculated as follows, assuming the width of the lane is 12 feet and vehicles' visible front wheels are within 4 feet from the lane marker at the same side:

$$|\varepsilon_A| \leq \frac{2}{12} \times 75\% \times (12i + 4) - 1 = 1.5i - 0.5 \text{ inches}$$

Assuming ε_M is less than 0.5 inch, then $|\varepsilon_L| \leq 1.5$ inches when the computation is for lane 1, the maximum relative errors of speed for different pairs of the actual speed and the segment length are shown in Table 1.

Max. Possible Relative Error		Actual Speed (mph)					
		10	20	30	40	50	60
Segment Length (feet)	20	3.58%	4.45%	6.24%	8.09%	10.01%	12.00%
	40	1.77%	2.19%	3.04%	3.91%	4.79%	5.69%
	60	1.17%	1.45%	2.01%	2.58%	3.15%	3.73%
	80	0.88%	1.08%	1.50%	1.92%	2.35%	2.78%
	100	0.70%	0.87%	1.20%	1.53%	1.87%	2.21%
	120	0.58%	0.72%	1.00%	1.27%	1.55%	1.83%

Table 1. Distribution of maximum possible relative errors

Case Study

A case study has been conducted for detector No.5 from ARAMPS (An **A**utomated **R**eal-Time Tr**a**vel Ti**m**e **P**rediction **S**ystem) project on I-70 eastbound in Maryland.

All 1,812 vehicles in lane 1 (the right lane) at detector 5, which covers a 2-lane freeway segment, were analyzed with the proposed video-based method with two reference lines 40.7 feet apart during the time period from 7:35AM to 8:45AM on 11/29/2005. A radar speed gun was used to measure some vehicles in the same time period.

Video-based Speed Measurement vs. Speed Gun: Comparison of Individual Vehicle

Speeds of 50 vehicles picked randomly were measured with a radar speed gun from 8:10AM to 8:23AM. Later, each of those 50 vehicles was identified in the video. A comparison of speeds from the video-based method and the speed gun was made for all 50 pairs. The speeds from the video-based measurement method range from 22.15 mph to 64.74 mph. The comparison between video-based method and speed gun measurement is shown in Table 2. The results indicate two sets of speed data match each other fairly good. Please note that the data from the speed gun is for reference only because the location of speed measurement may vary slightly between different observations.

Speed Category from Video	Average	Standard Deviation	Max. Positive Difference	Max. Negative Difference	Count
20-35	0.00	1.24	1.56	-1.88	9
40-55	-0.77	1.53	1.70	-3.31	13
>55	0.30	1.81	4.50	-2.13	28

Table 2. Speed Differences between Video-based Measurement and Speed Gun (mph)

Comparison between All Three Methods

Speeds have also been measured by a speed gun for most vehicles for about 14 minutes (8:01AM to 8:08AM and 8:25AM to 8:32AM). A total of 380 vehicles were detected by the detector of which 337 vehicles (88.68%) were measured by the speed gun. The video-based method detected 385 vehicles in the same time period. Each single measurement point from the speed gun was recorded with a timestamp from a handheld GPS receiver. The speeds from the video-based method and the speed gun have been averaged to match 27 30-second intervals in the 14-minute period from the detector. All three methods show consistent speed range when speeds are above 55 mph (Table 3).

Speed Category from the Video	Average Speed (mph)			# of Intervals
	Video-based	Speed gun	Detector	
50-55	53.91	53.09	58.33	3
55-60	57.51	56.94	59.44	16
>60	60.73	59.66	62.63	8

Table 3. Average Speeds from Three Measurement Methods (mph)

Video-based Measurement vs. Detector

Finally, 140 30-second intervals were determined in the video to match the intervals from the detector for the entire data collecting period from 7:35AM to 8:45AM. As shown in Table 4, detector data was close to those from the video-based method when speeds from the video are above 55mph, which is the speed range used to make the latest speed calibration on the detector. However, large variances have been found when speeds from the video are less than 55mph. The results indicate further calibration for lower speed conditions is needed for this detector to provide reliable speed data for the travel time prediction system.

Speed Category from Video	<25	25-35	35-45	45-55	>55
Average Difference	14.04	17.93	15.05	8.48	3.38
Standard Deviation	12.96	3.27	2.37	3.31	3.16
Max. Positive Difference	32.45	22.50	40.50	13.65	9.38
Max. Negative Difference	-2.41	-8.25	-35.03	-2.08	-4.59
Interval Count	5	34	23	27	47

Table 4. Speed Differences between Video-based Measurement and Detector (mph)

Conclusions

A video-based speed detection system, which is cost-efficient and reliable, has been developed in this study. Based on the detailed analysis on possible errors, the system is proved to provide reliable speed detection for all speed range under detection conditions mentioned in this paper. A case study shows that the system output is consistent with speed gun measurements and large variances have been identified from one detector when speed is less than 55 mph. The result indicates a further speed calibration is required for that detector to provide reliable speed data.

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