Using Data from a DriveCam Event Recorder to Reconstruct a Vehicle-to-Vehicle Impact

2013-01-0778

Published
04/08/2013

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doi:10.4271/2013-01-0778

ABSTRACT

This paper reports a method for analyzing data from a DriveCam unit to determine impact speeds and velocity changes in vehicle-to-vehicle impacts. A DriveCam unit is an aftermarket, in-vehicle, event-triggered video and data recorder. When the unit senses accelerations over a preset threshold, an event is triggered and the unit records video from two camera views, accelerations along three directions, and the vehicle speed with a GPS sensor. In conducting the research reported in this paper, the authors ran four front-to-rear crash tests with two DriveCam equipped vehicles. For each test, the front of the bullet vehicle impacted the rear of the stationary target vehicle. Each of the test vehicles was impacted in the rear twice - once at a speed of around 10 mph and again at a speed around 25 mph. The accuracy of the DriveCam acceleration data was assessed by comparing it to the data from other in-vehicle instrumentation. We found that, for in-line front-to-rear crashes like those tested in this paper, the video, GPS and acceleration data reported by the DriveCam systems is useful for reconstructing crashes, provided that the reconstructionist accounts for potential limitations in the data.

INTRODUCTION

A DriveCam unit is an aftermarket, in-vehicle, event-triggered video and data recorder that is mounted to a vehicle's windshield in the area of the rear view mirror (Figure 1). A DriveCam unit contains a GPS sensor that measures speed, accelerometers that measure longitudinal, lateral, and vertical accelerations, and two cameras that record video. One of these cameras looks forward through the windshield and the other looks rearward at the vehicle occupants. If a DriveCam unit measures an acceleration that exceeds a preset threshold, it defines an event and stores video, acceleration and speed data. This data can be accessed and analyzed to evaluate the performance of the driver and to determine the sequence of events that led to the DriveCam event being triggered.

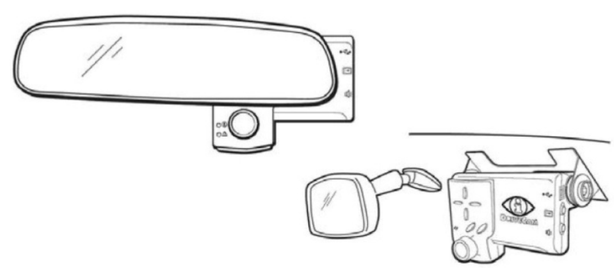

Figure 1. Schematic Depicting a Typical DriveCam Unit

The research reported in this paper led to the development of a method for using the data from a DriveCam unit to determine impact speeds and velocity changes for in-line vehicle-to-vehicle impacts. For this study, four front-to-rear impact crash tests were conducted with two DriveCam equipped vehicles. For each test, the front of the bullet vehicle impacted the rear of the stationary target vehicle. Each of the test vehicles was impacted in the rear twice - once at a speed of around 10 mph and again at a speed around 25 mph.

The DriveCam units recorded video, acceleration and speed data during the testing. For each test, DriveCam video, acceleration, and speed data was used to calculate a bullet vehicle impact speed and a change in velocity (ΔV) for each of the vehicles. The DriveCam accelerations, calculated ΔVs and bullet vehicle impact speeds were then compared to the accelerations and speeds recorded by other instrumentation present during the tests.

The data from a DriveCam event is typically provided by DriveCam in the form of a DCE file. These files can be viewed in an event player downloaded from DriveCam's website (www.drivecam.com). We obtained a DCE file for each DriveCam unit in each of our four tests and accessed the video and acceleration data in these files through the DriveCam Event Player. The image in Figure 2 is a sample of the display available in the DriveCam Event Player. The acceleration data is displayed in the graphs at the top of the Event Player and video from the two cameras is shown at the bottom. The units that we used in our testing captured a total of 30 seconds of data for each event, consisting of 18 seconds before and 12 seconds after the event trigger.

Figure 2. Sample of DriveCam Event Player Display

METHODOLOGY

On August 10, 2012, the authors conducted four front-to-rear impact crash tests on a flat and dry asphalt surface at the Denver Police Academy. These tests utilized two DriveCam equipped vehicles - a 2002 Chevrolet Cavalier and a 2003 Chevrolet Malibu - which are depicted in Figures 3 and 4. In each test, the front of the bullet vehicle impacted the rear of the stationary target vehicle. Each of the test vehicles was impacted in the rear twice. Table 1 identifies the bullet and the target vehicle for each test and reports the impact speeds for the bullet vehicle.

Figure 3. 2003 Chevrolet Malibu

Figure 4. 2002 Chevrolet Cavalier

Table 1. Summary of Tests

Test Number	Bullet Vehicle	Target Vehicle	Impact Speed (mph)
1	Malibu	Cavalier	10.9
2	Malibu	Cavalier	23.7
3	Cavalier	Malibu	10.4
4	Cavalier	Malibu	25.0

In the two lower speed tests, individuals on our research team drove the bullet vehicles. For the two higher speed tests, we utilized a push vehicle to accelerate the bullet vehicles up to the target impact speed of 25 mph. After each test, the damage to the vehicles was documented. As an example, Figure 5 below depicts the damage to the vehicles after Test #4.

Figure 5. Damage to the Test Vehicles after Test #4

In all four tests, the Malibu was equipped with a single DC-3P DriveCam unit and the Cavalier was equipped with a DC-3P and a DC-3 unit. All three DriveCam units recorded video, acceleration, and speed data for each test. The accelerations were accessible at a 20-Hz sampling rate and the video at 4 frames per second for each of the cameras. The DC-3P units measured the vehicle speed using an independent GPS sensor whereas the DC-3 unit measured speed via a GPS sensor embedded in the units cellular modem. The acceleration levels at which a DriveCam event will be triggered are user defined. For this test series, we set the longitudinal threshold to 0.6 g and the lateral threshold to 0.55 g. In addition to the DriveCam units, we also equipped each vehicle with two GoPro cameras to approximate the view of the DriveCam cameras. The two DriveCam units and the two GoPro cameras on the Cavalier are shown in Figure 6.

Each test vehicle was also instrumented with a Gulf Coast Data Concepts X16-2 accelerometer that captured tri-axial accelerations at 400-Hz. For our analysis, we aligned the accelerometer's x-direction to the car's longitudinal axis and the y-direction to the car's lateral axis. At the beginning of each test, the accelerometer was triggered to record data with the vehicle stationary for a brief period. The data was first rotated such that during the stationary period the average acceleration in the x-direction was equal to the magnitude of gravity on the vehicle's longitudinal axis due to the slight grade of the test surface. We repeated this process for the y-direction. For the accelerometer on the bullet vehicles, we examined the longitudinal acceleration signal during the first portion of the test as the vehicle was accelerating and rotated the data in the vehicles yaw plane such that the acceleration was primarily along the longitudinal axis [1]. We also filtered the data using a double second order low-pass Butterworth filter. This Butterworth filter consisted of multiplying the cutoff frequency by 1.25 and using a filter-flip-filter-flip numerical filter routine [2]. The end result was a filter that responded within the response corridor architecture found in SAE Standard J211. The cutoff frequency we chose was based upon the accelerometer's sample rate of 400-Hz. This resulted in a Channel Filter Class 36 with a cutoff frequency of 60 Hz.

Figure 6. DriveCam and GoPro Cameras Mounted to the Cavalier Windshield

The bullet vehicle in each test was equipped with a RaceLogic VB20SL3 20-Hz GPS data acquisition system (VBOX). The VBOX utilized three GPS antennas to measure the test vehicle's translational and angular positions and its speed throughout the tests. These GPS antennas were mounted to a frame system with one meter of separation between primary to pitch and primary to roll antennas. The frame itself was mounted to the bullet vehicle via angled magnetic feet and tie-down straps around the roof (Figure 7).

Figure 7. Rail Mounting System for VBOX Antennas

DATA ANALYSIS

In the data analysis portion of this research, our goal was to develop analysis procedures that would maximize the accuracy and usefulness of the DriveCam data for determining the impact speed and ΔVs for the vehicle-to-vehicle collisions examined in this paper. In accomplishing this, we developed two different methods - one for analyzing the data from DriveCam units on the bullet vehicles and another for the data from DriveCam units on the target vehicles. The need for two methodologies was driven by our finding that the GPS data was generally less reliable when the vehicle was initially stationary and then experienced a sudden change in velocity. In developing these two procedures, we compared the results to the data from the other instrumentation on the test vehicles. The goal was to establish procedures that would be suitable in a real-world case when there was no additional instrumentation on the vehicle.

Bullet Vehicle Analysis

When analyzing the DriveCam data from the bullet vehicle DriveCam units, we utilized the speed data reported by the DriveCam GPS sensors (reported with a frequency of 1-Hz). Analysis of the data from these units involved the following steps: (1) The acceleration, speed and video data was obtained from the DCE files. (2) The video data was examined to establish constraints on the analysis of the acceleration data and GPS speed data. For the tests analyzed in this research, these constraints took the form of two points in time at which we were able to establish from the video that the vehicle was stopped. One of these points in time occurred before the impact and one after. For instance, the DriveCam video from the bullet vehicle (Malibu) for Test #1 showed that the vehicle was stopped at time −9.25 seconds and again at time +6.0 seconds. (3) The longitudinal acceleration data from the DriveCam unit was then integrated backwards in time using the post-impact stop time as the starting point. The resulting velocity curve was then compared to the GPS speed data from the DriveCam unit. The graph of Figure 8 depicts this comparison for Test #1.

This graph reveals several features of the DriveCam data. First, the GPS speed data lags slightly behind the speed calculated from the acceleration data. This is not surprising since the DriveCam GPS sensor samples positions at 1-Hz and so the reported speed is an average value over a one second interval. The acceleration data is reported by the DriveCam unit at 20-Hz, so one would expect changes in speed to be apparent sooner in the acceleration data than in the GPS speed data. During gradual changes in speed, the GPS speed appears to lag behind the speed calculated from the accelerations by around a half second.

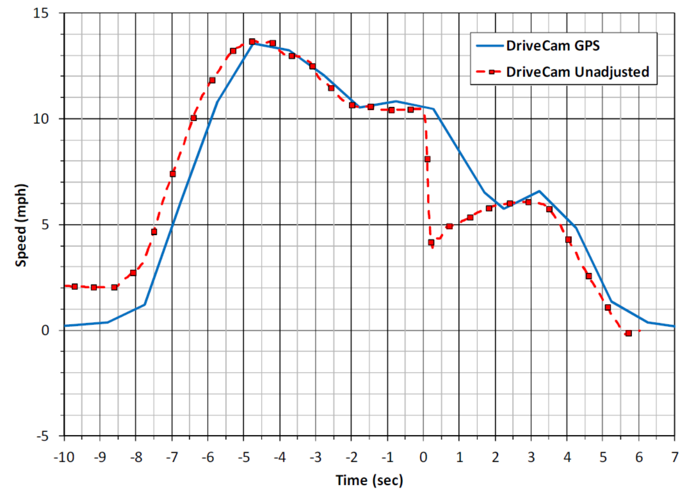

Figure 8 Comparison of Bullet Vehicle Speed as Measured by the DriveCam GPS Sensor and as Obtained from Integration of the DriveCam Accelerations

Second, the DriveCam GPS data alone does not provide an accurate estimate of the ΔV associated with the impact. The impact is apparent near time zero in the sudden drop of the speed curve obtained from integration of the DriveCam accelerations. The corresponding drop in the GPS speed data is much more gradual and ultimately fails to capture the full change in velocity experienced by the vehicle.

Finally, the speed curve obtained from integration of the DriveCam accelerations only satisfies one of the known velocity constraints of the DriveCam video, that the bullet vehicle (Malibu) was stopped at time +6.0 seconds. However, it shows the vehicle still moving at time −9.25, when the video shows the vehicle should be stopped. This discrepancy with the video record can be resolved by applying a small offset adjustment to the entire set of DriveCam longitudinal acceleration data. A similar method was presented in Reference 3. Such an adjustment makes physical sense as a correction to a small misalignment between the orientation of the vehicle and the orientation of the DriveCam accelerometer. In conducting our analysis, we varied the size of the applied correction until we satisfied the known speed constraints. Figure 9 shows that applying a correction of +0.008 g to the accelerations from the bullet vehicle in Test #1 resulted in the new velocity curve satisfying the speed constraints from the video.

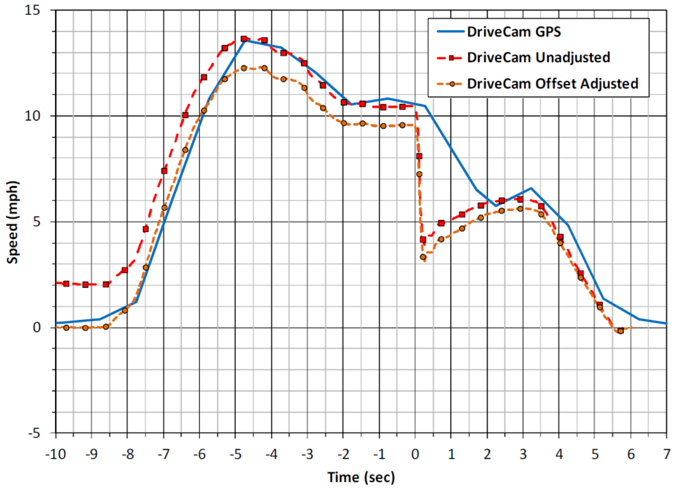

Figure 9. Comparison of Bullet Vehicle Speed as Measured by the DriveCam GPS Sensor, as Obtained from Integration of the DriveCam Accelerations, and as Obtained from the Offset Adjusted DriveCam Accelerations

This offset adjustment, however, lowers the magnitude of the entire curve such that the adjusted speed curve falls below the DriveCam GPS speed a significant portion of the time. To remedy this, we applied a gain adjustment to the acceleration by multiplying each acceleration value by a factor slightly greater than one so that the magnitude of the adjusted speed curve just prior to impact more closely matched the GPS curve just prior to impact. If a GPS speed data point was taken by the DriveCam unit between time 0.0 and +0.5 seconds, we used that speed to dictate the magnitude of the gain adjustment. If a GPS speed data point was not available in this time frame, we used the closest point before time zero. After the gain adjustment, we sometimes had to reapply the offset adjustment, and iterate between the two adjustments until all conditions were met.

An amplification of the DriveCam acceleration data is reasonable given that, with a 20-Hz acceleration signal (1 data point every 50 milliseconds), the peak acceleration is likely to be missed in an impact that will typically last only 100 to 200 milliseconds. This concept is presented below in Figure 10, which compares the DriveCam acceleration data to the acceleration data from the 400-Hz accelerometer and the calculated acceleration from the VBOX for Test #1. Adjusting the offset and gain in the DriveCam acceleration data in this manner produced the most consistently accurate speed curves across all four tests. Figure 11 shows the adjusted speed curve after a gain adjustment of 1.10 and an offset adjustment of 0.008 g were applied to the DriveCam accelerations.

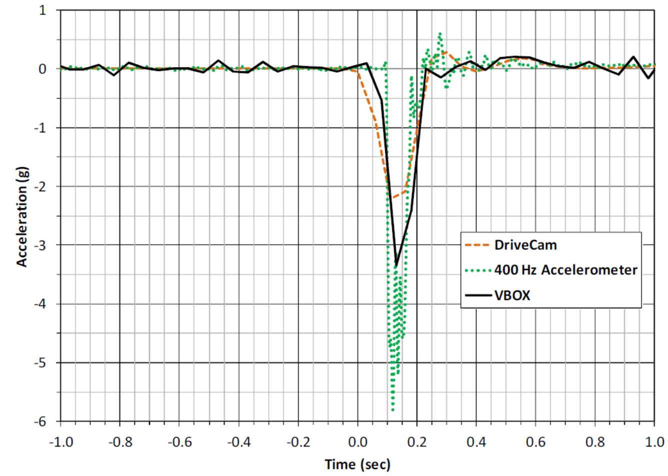

Figure 10. Acceleration Data from the Bullet Vehicle in Test #1, as Measured by the DriveCam Unit, the 400-Hz Accelerometer, and as Calculated from the VBOX Data

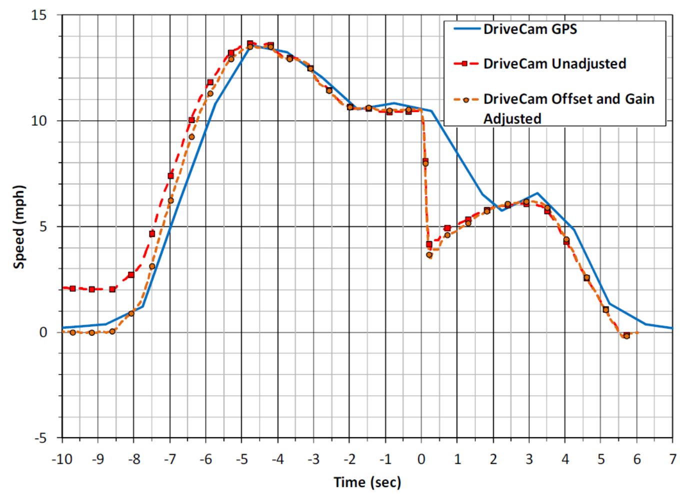

Figure 11. Comparison of Bullet Vehicle Speed as Measured by the DriveCam GPS Sensor, as Obtained from Integration of the DriveCam Accelerations, and as Obtained from the Offset and Gain Adjusted DriveCam Accelerations

To determine the accuracy of this method just discussed, we compared the speed curves calculated from the adjusted and non-adjusted DriveCam acceleration data to the speeds that were measured by the VBOX data acquisition system. As is illustrated in Figure 12, the speed calculated from the adjusted DriveCam acceleration data more closely matches the VBOX data than the speed calculated from the non-adjusted DriveCam acceleration data. A comparison of these data sets to the VBOX data reveals that, in our tests, adjusting the DriveCam acceleration in this manner generally resulted in a more accurate match of the ΔV associated with the impact as well as a more accurate pre-impact speed of the bullet vehicle. Table 3 shows the gain and offset adjustment factors used.

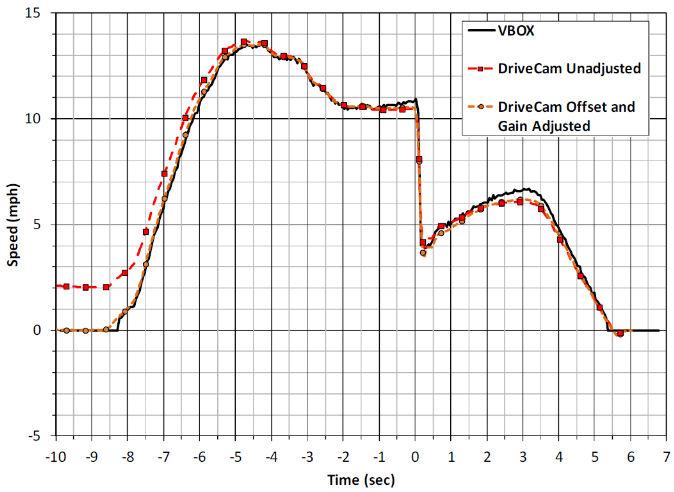

Figure 12. Comparison of Bullet Vehicle Speed as Measured by the VBOX, as Obtained from Integration of the DriveCam Accelerations, and as Obtained from the Offset and Gain Adjusted DriveCam Accelerations

Table 3. Gain and Offset Adjustments used to Adjust the DriveCam Acceleration Data

Test Number	DriveCam Unit	Gain Adjusment Factor	Offset (g)
1	Malibu DC-3P	1.10	0.008
2	Malibu DC-3P	1.21	0.006
3	Cavalier DC-3P	1.08	0.008
4	Cavalier DC-3P	1.16	0.017

To test the accuracy of this analysis procedure, we compared the results to those from the other instrumentation on the bullet vehicle - namely the 400-Hz accelerometer and the VBOX data. Figures 13 and 14 summarize the bullet vehicle impact speeds and velocity changes determined from this instrumentation for each of the four tests. Figure 15 compares the impact speed as determined from the DriveCam GPS sensor to the average impact speed from the other instrumentation. Figures 16 and 17 then compare the bullet vehicle impact speeds and velocity changes determined from the raw and adjusted DriveCam data to the average of these values from the other instrumentation. In Figures 15, 16 and 17, the bar representing the instrumentation average also includes an error bar showing the range of the value from the other instrumentation. In Test #4, the VBOX velocity decreased much less rapidly following the impact than what was expected and what was measured by the DriveCam and the accelerometer. We concluded that a VBOX antenna likely slid forward during the impact, artificially increasing the measured speed during the period where the antenna was sliding. For this reason, we disregarded the VBOX ΔV for this test and only compared the analysis of the DriveCam data to the ΔV as determined from the 400-Hz accelerometer.

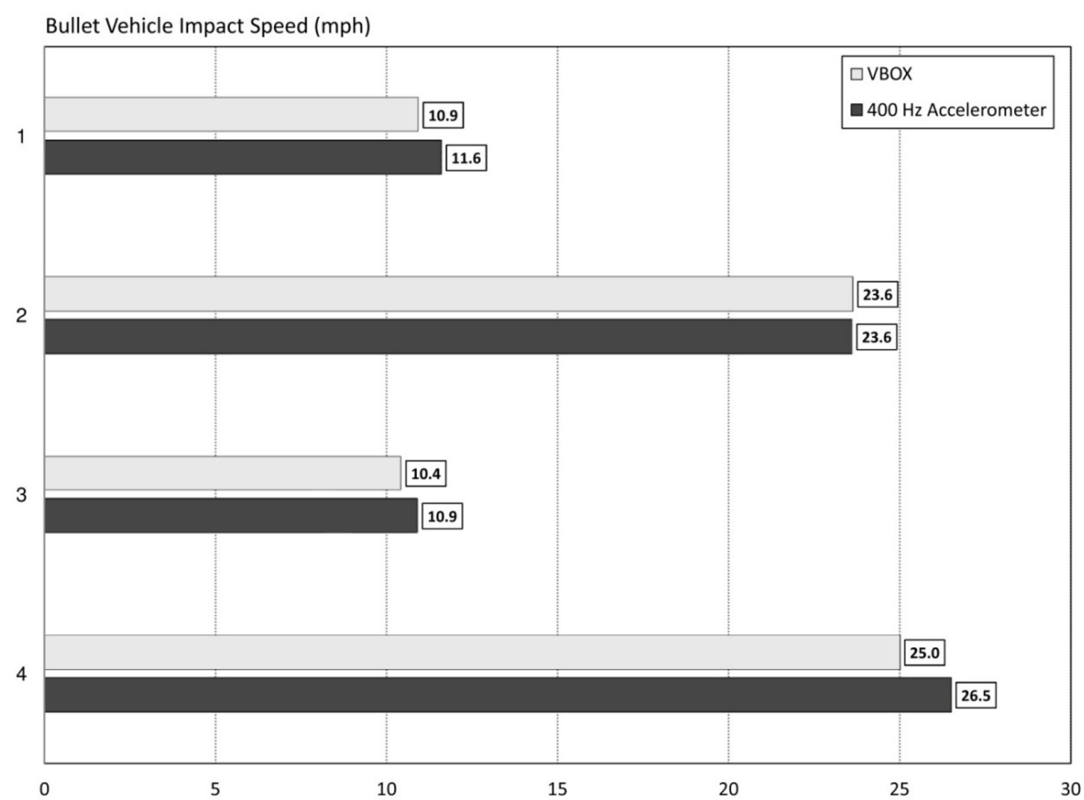

Figure 13. Bullet Vehicle Impact Speeds as Determined from the VBOX and 400-Hz Accelerometer Data

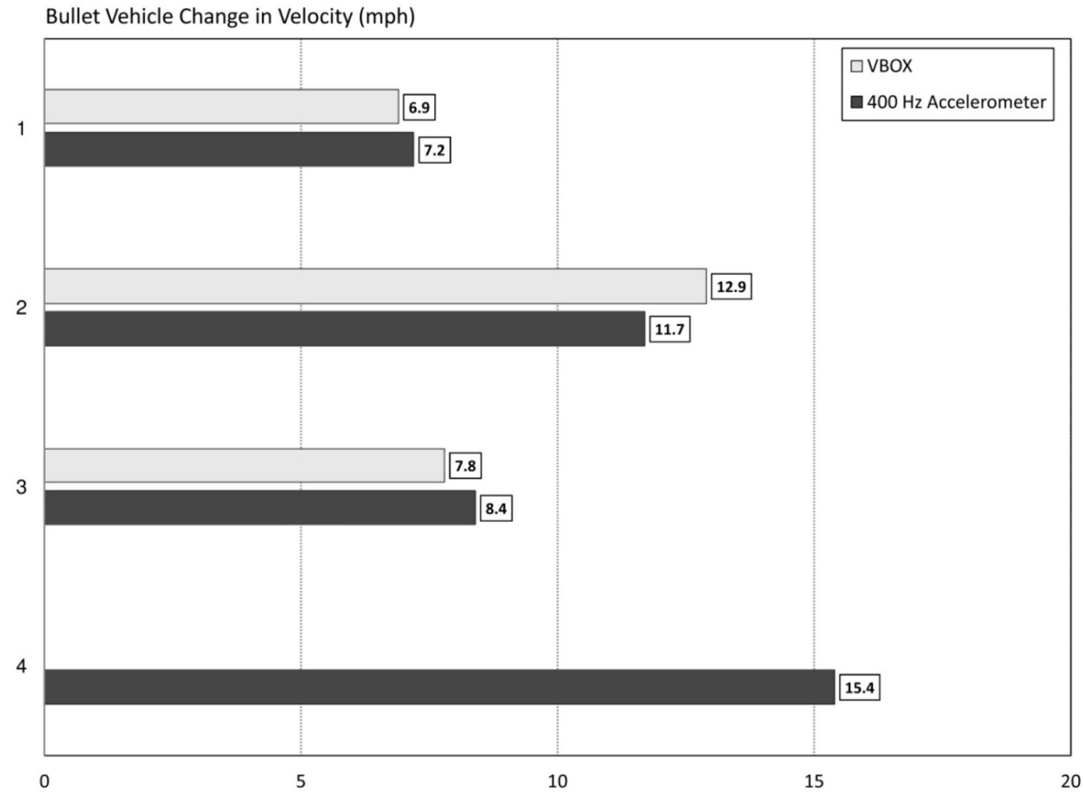

Figure 14. Bullet Vehicle ΔV as Determined from the VBOX and 400-Hz Accelerometer Data

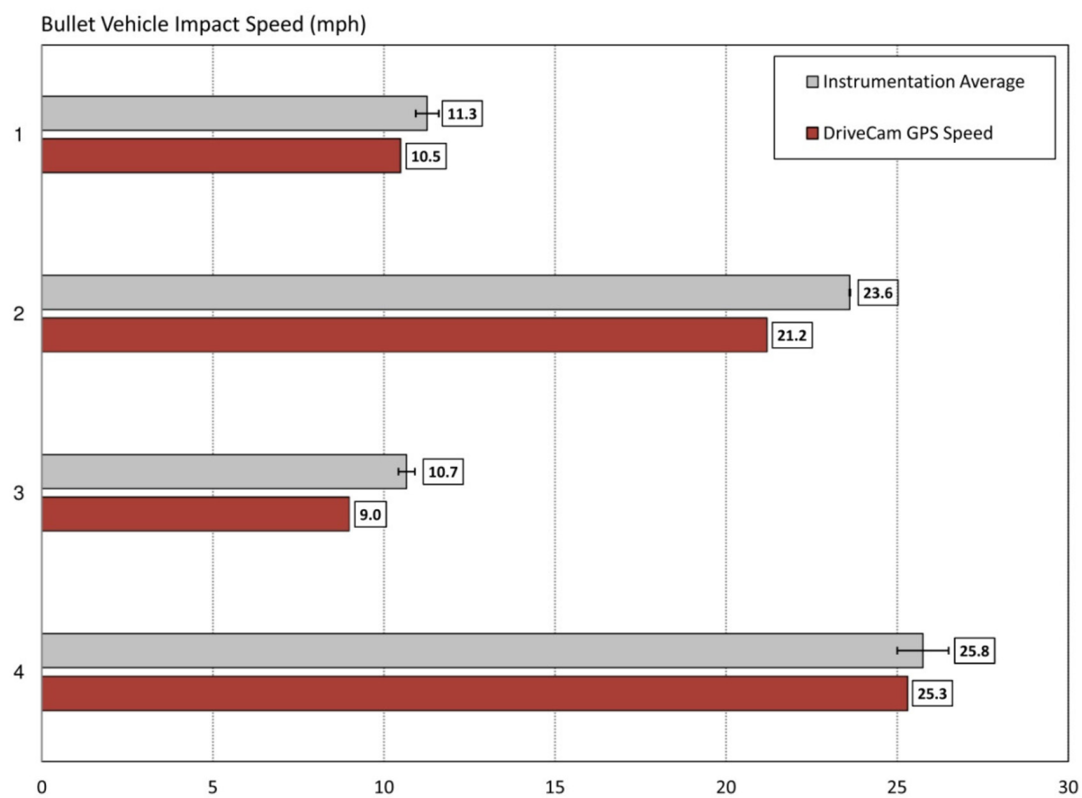

Figure 15. Comparison of DriveCam GPS Impact Speed to Impact Speed from Other Instrumentation

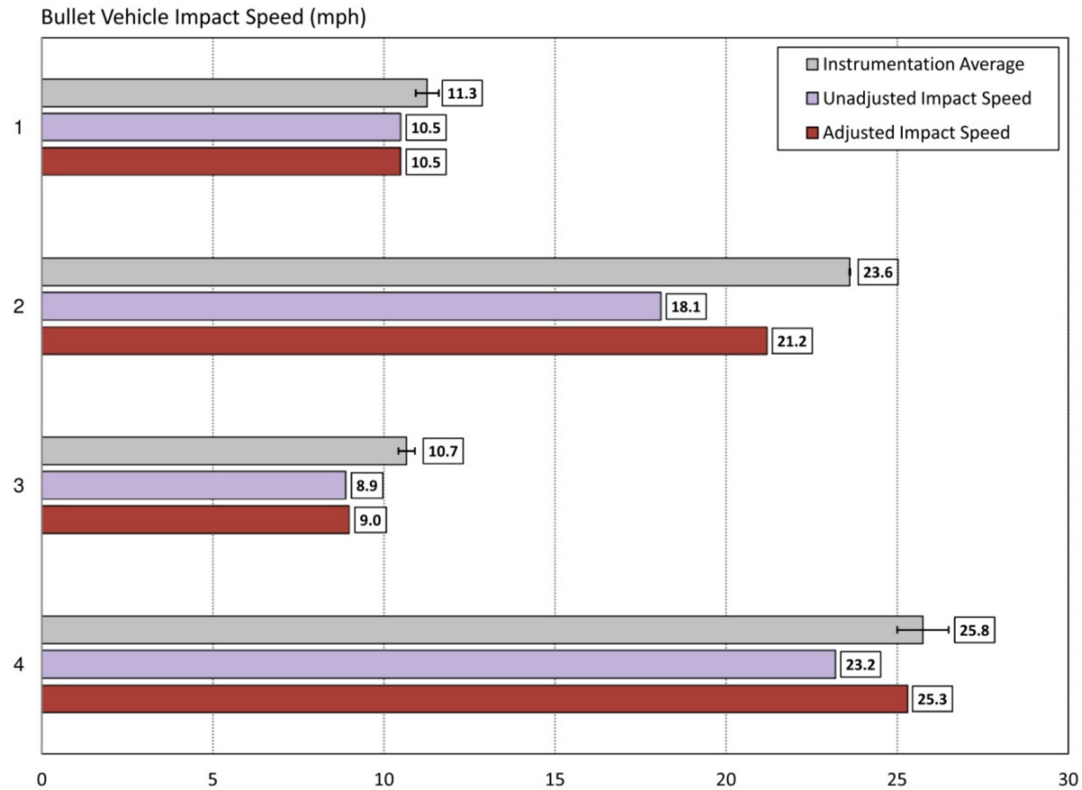

Figure 16. Comparison of DriveCam Impact Speed and Adjusted DriveCam Impact Speed to VBOX Measured Impact Speed

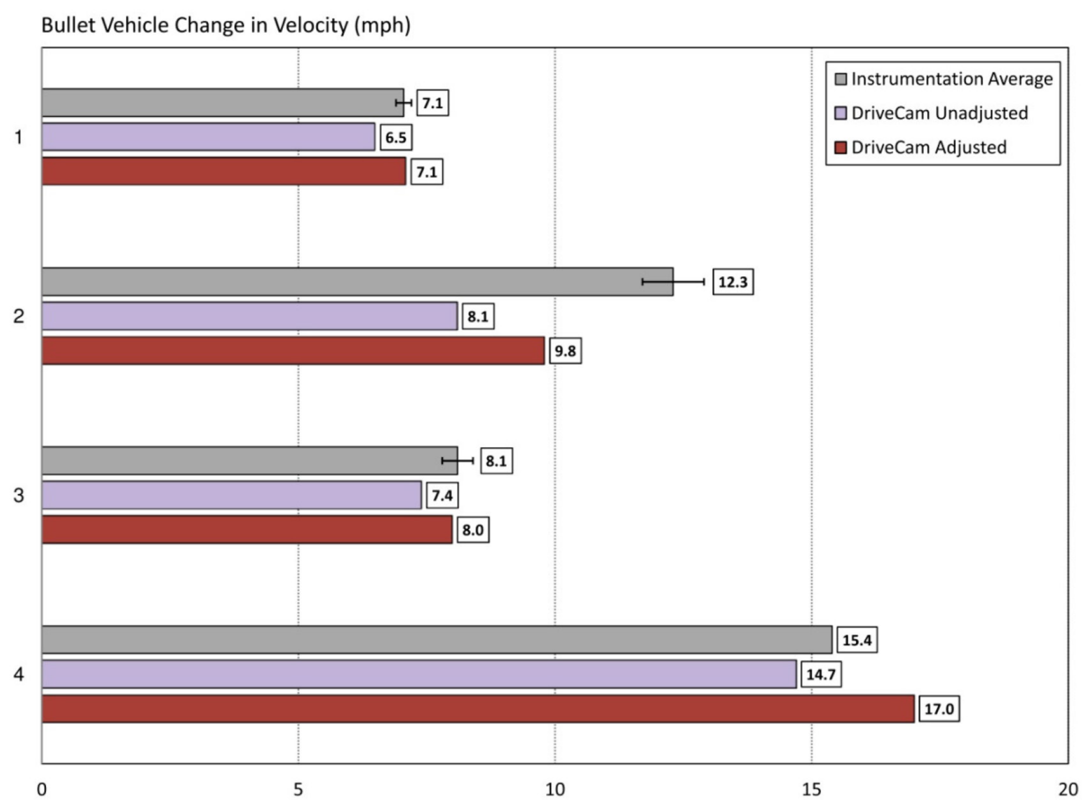

Figure 17. Comparison of DriveCam ΔV and Adjusted DriveCam ΔV to ΔV from Other Instrumentation

Target Vehicle Analysis

For the second analysis method developed in this research, we analyzed the post-impact speed of the target vehicles by determining the change in position of the vehicle between specific frames of the DriveCam video. In conducting this analysis, we used a photogrammetric method known as camera reverse projection or camera-matching [4, 5]. Completing this photogrammetric analysis involved the following steps:

1. A Sokkia total station was used to digitally map the test location. This mapping focused on features of the test area that would be visible to the DriveCam cameras such as the test surface, cones, light poles, homes and trees in the background.

2. Our mapping data was used to create a three-dimensional computer model of the test area.

3. We analyzed the distortion in the DriveCam videos by recording video of an object with a known pattern. This allowed us to adjust for the image distortion when we later analyzed frames of the DriveCam video from the crash tests [6].

4. The three-dimensional computer model of the test area was imported into Autodesk® 3ds Max® and computer-modeled cameras were created to view the scene model from perspectives that were similar to the view of the DriveCam video frames being analyzed.

Figure 18. Example of Results from the Camera-Matching Photogrammetry Process

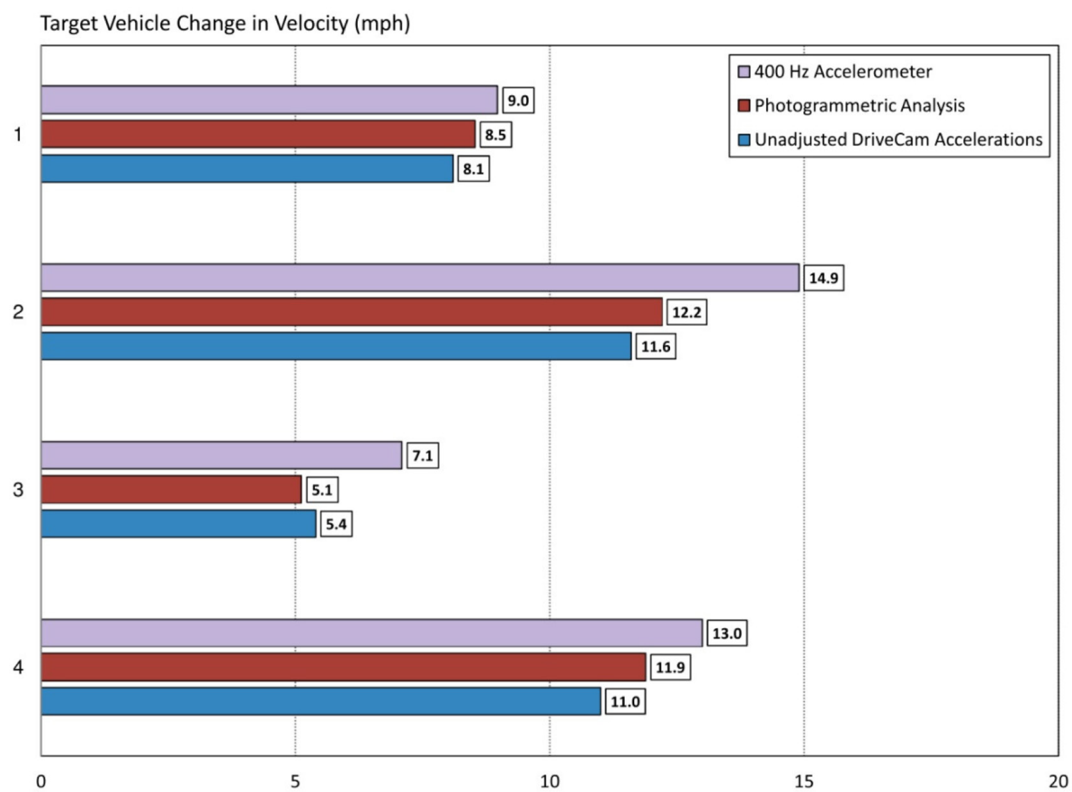

Figure 19. Comparison of ΔV from Photogrammetric Analysis and DriveCam Accelerations to ΔV from 400-Hz Accelerometer

5. The DriveCam video frames from the staged collisions were then imported into Max® and designated as background images for the corresponding computer-modeled camera view. The location, focal length and target location of the computer-modeled camera was adjusted until there was an overlay between the computer-generated environment model and the environment shown in the video frame. Once the focal length of each camera was established, it was held constant in this analysis. Figure 18 below depicts the results of this process for one frame of video from Test #3.

6. Once an overlay was achieved for two frames of DriveCam video, the distance between the two camera positions for these frames was calculated and used with the corresponding times for these frames to calculate the average speed of the vehicle between those frames.

7. To calculate the speed of the vehicle just after impact, we calculated the average vehicle deceleration from the DriveCam acceleration data between the two frames that were analyzed. We then applied that acceleration rate to the calculated speed to extrapolate it back to a time immediately after the impact. We chose to calculate the speed at a time of +0.2 seconds, hypothesizing that, if the impact time corresponded to approximately time zero, then the impacts would be complete 0.2 seconds after time zero.

This process was used to calculate the velocity changes experienced by the target vehicles in each of the four crash tests. Figure 19 compares the target vehicle ΔV calculated through this photogrammetric analysis to the ΔV that would be calculated using unadjusted DriveCam accelerations and the 400-Hz accelerometer data.

DISCUSSION

As has been discussed previously in Reference 3, DriveCam video footage provides a means of establishing velocity constraints that any other reconstruction analysis must satisfy. The simplest example of this is when the video shows a vehicle in a stopped position. Whatever other analysis method is applied in analyzing a crash, that analysis method should show the vehicle stopped at the same time shown in the video. In our analysis of the four tests reported in this paper, it was the video record that allowed us to identify a slight delay in the speeds reported by the DriveCam GPS sensor. Once this delay was identified, then the GPS speed data could be used to impose additional reasonable speed constraints on other forms of analysis. In the four tests reported in this paper, the GPS sensor on the DriveCam units yielded an impact speed for the bullet vehicle that was within 2.5 mph of the impact speed determined from the other instrumentation on the vehicle.

For the four crash tests reported in this paper, analysis of the raw DriveCam acceleration data resulted in calculated impact speeds and ΔVs that were lower than those measured by the VBOX data acquisition system and calculated with 400-Hz accelerometer data. This paper detailed two methods that attempted to increase the accuracy of using the DriveCam acceleration data for accident reconstruction purposes.

The first method involved adjusting the gain and offset of the DriveCam acceleration data by using the speed constraints established with the DriveCam video and GPS data. This method is advantageous in that, unlike the second method, it does not require mapping of the accident site for photogrammetric analysis. Rather, the GPS speed reported by the DriveCam unit establishes the necessary gain adjustment factor. As shown in Figures 16 and 17, for the lower speed tests, this adjustment procedure had little effect on the calculated impact speed but improved the accuracy of the calculated ΔVs. For the higher speed tests, the adjustment procedure improved the calculated impact speeds, but had a more ambiguous effect on the calculated ΔVs.

The second analysis method presented in this paper involved photogrammetric analysis of the video data. This method resulted in calculated ΔVs that were more accurate than simply using unadjusted accelerations from the DriveCam unit for three of the four tests. However, this analysis procedure still resulted in calculated ΔVs that were generally lower than those calculated from the 400-Hz accelerometer data. The magnitude of the underestimation varied between 0.5 and 2.7 mph.

Further research would be necessary to uncover the source of this underestimation. Certainly one possibility is potential inaccuracy in the frame rate. It is possible that the actual time between frames could be slightly more or less than 0.25 seconds and this could introduce some error in the calculated speeds. Another potential source of error is the difficulty introduced into the process of matching the survey to the video by the relative uniformity of the test surface. In other words, the test surface lacked the kind of unique, identifiable features on which the camera-matching technique depends. The surface offered only limited possibilities for identifying common features between the video and our survey that could be used in achieving an overlay between the survey and the video. Ideally, for an accurate camera match, the video would contain unique features in both the background and foreground, but for our tests, the primary unique features were only in the background. Yet another possible source of error was the relatively low resolution of the DriveCam video (640×368) that made it more difficult to achieve a match with distant objects (those beyond the test surface in the background) visible in the video. These last two issues could become less significant with a different test surface or accident location, but further research would be necessary to demonstrate this.

A disadvantage of this second analysis method is the need to map the accident site. In lieu of such analysis, a reconstructionist could simply apply a reasonable range of offset and gain adjustment factors to the DriveCam acceleration data to produce a likely range of impact speed and ΔV values. The data presented in this paper supports the notion that such a method would result in a more accurate analysis than by considering only the unadjusted DriveCam acceleration data, but again, further testing and analysis would be necessary to demonstrate this.

CONCLUSIONS

1. DriveCam video footage is useful for identifying constraints that other forms of analysis must meet. For example, in the four tests reported in this paper, the video clearly showed points in time when the vehicles were stopped.

2. For the four tests reported in this paper, the data from the DriveCam GPS sensors yielded the impact speed of the bullet vehicle to within 2.5 mph of the speed reported by other instrumentation. However, the sampling rate of the DriveCam GPS sensors was too low to yield an accurate determination of the ΔV.

3. For the four tests reported in this paper, the raw acceleration data from the DriveCam units resulted in calculated impact speeds that were consistently lower than those measured by the DriveCam GPS sensors and the VBOX and calculated from the 400-Hz accelerometer data.

4. For the four tests reported in this paper, the raw acceleration data from the DriveCam units resulted in calculated bullet vehicle ΔVs that were consistently lower than those measured by the VBOX and calculated with the 400-Hz accelerometer data.

5. For the four tests reported in this paper, the analysis procedure developed to adjust the DriveCam data from the bullet vehicle units generally produced more accurate impact speeds and ΔVs than using the raw DriveCam accelerations. For the lower speed tests, the adjustment procedure had little effect on the calculated impact speed but improved the accuracy of the calculated ΔV. For the higher speed tests, the adjustment procedure improved the calculated impact speeds, but had a more ambiguous effect on the calculated ΔVs.

6. For the four tests reported in this paper, the analysis procedure developed to photogrammetrically analyze the DriveCam video resulted in calculated target vehicle ΔVs that were consistently lower than the ΔVs determined through analysis of the 400-Hz accelerometer data. The difference ranged between 0.5 to 2.7 mph.

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ACKNOWLEDGEMENTS

We would like to acknowledge and thank the following individuals at DriveCam for providing the DriveCam units utilized in this testing and for taking the time to help us with technical questions related to these units and the interpretation of their data: Del Lisk, Syrus Nemat-Nasser, Phil Schweizer, and Dan Lambert. We also thank the Denver Police Academy for allowing us to use their facility to conduct our crash tests. And finally, we thank Amy Stewart, Toby Terpstra, and Alireza Hasemian of Kineticorp who assisted with obtaining the tests vehicles and with the photogrammetric analysis presented in the paper.

The Engineering Meetings Board has approved this paper for publication. It has successfully completed SAE's peer review process under the supervision of the session organizer. This process requires a minimum of three (3) reviews by industry experts.

ISSN 0148-7191

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