iPhone Accelerometer Results From 45 Emergency Braking Tests on Snow-Covered Roads

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Recently Gorski Consulting has been involved in the development a system of video cameras and iPhones for the purpose of data acquisition from live drive-throughs of roadways in south-western Ontario, Canada. A number of recent articles have been uploaded to the Gorski Consulting website (www.gorskiconsulting.com) describing variations of this system.

Figure 1: Example of a set of synchronized videos used in previous testing, similar to the present set-up.

An important part of this research has been to evaluate the functioning of the iPhone's accelerometer and gyros that are accessed through low-priced "apps" available through the iPhone distributor. Equally, data on the braking performance of vehicles on icy, snow-covered and gravel roadways is needed if the causes of loss-of-control collisions are to be better understood. Thus these were the primary reasons why Gorski Consulting conducted further emergency braking tests on February 8, 2013, just as a snow storm was ending its passage through south-western Ontario.

The instrumentation used in our testing has been previously discussed in website articles such as "Description of Multiple Video Cameras and iPhone Accelerometers

Used in Brake Testing And General Vehicle Motion Analysis" (uploaded to the Gorski Consulting website on February 7, 2013) and this article can be consulted for further descriptions of that instrumentation.

The present testing was conducted along a number of roads within the City of London, Ontario, as well as several rural highways in its vicinity. The emergency braking tests were conducted at speeds between 22 and 70 km/h, although a majority were in the range of 50 to 70 km/h. The ambient temperature displayed on the test vehicle's (2007 Buick Allure) instrument cluster was approximately -6 degrees Celsius. All but one test (Test #4, on downgrade) were performed on relatively level road surfaces. The majority of the tests were performed on hard-topped (asphalt and tar & chip) surfaces although there were several conducted on gravel roads. Four tests were conducted during a reversing motion. One test (Test #8) was conducted in very deep snow (approximately 6 inches) at a speed of 45 km/h. This wide variation of testing was employed to study the effects on the display of the iPhone accelerometer and whether there would be certain instances where the results might be in error.

An unusual decision on our part was to obtain the accelerometer results by videotaping the iPhone's display screen. The more conventional approach would have been to send a file via e-mail to our computer which could then be imported into an Excel spreadsheet. Although this decision made the process more time-consuming and possibly precarious, it was made because we were searching for a reliable method whereby there could be a video record available of the precise road conditions and driver actions that triggered the specific acceleration being displayed. One of the disadvantages of reviewing a file sent via e-mail, or any file generated from previous versions of accelerometers was that it was difficult to match the file results to a precise location of road feature or action by the driver. Video has the theoretical advantage of providing that detail by incorporating a synchronized view of the accelerometer display precisely as the vehicle is observed passing over a specific road feature or precisely when the driver is observed conducting a specific action.

We made the decision to document the iPhone's longitudinal acceleration at every 5 frames of a second so that the documentation of data was not overwhelming. Thus, at a video frame rate of 30 fps, there would only be 6 data points per second and that was rather low. However, we wanted to explore what effects this would have on the average g value that was eventually calculated from each braking test. Documentations every 2nd frame and at every frame were also conducted for some of the tests so that we could see the resultant change in calculated g.

A video camera pointed at the brake pedal of the test vehicle meant that we could detect, within a 30th of a second, when the brake pedal was first contacted in the braking test. Another video camera placed underneath the vehicle's front bumper provided a very close-up view of the road surface and therefore we obtained a reasonably precise (within a 30th of a second) record of when the vehicle came to rest. This combination provided a reasonably precise recording of the total time of deceleration and thus an average g value for the test could be obtained. By comparing the average g value from this video record to the average g value obtained from the iPhone accelerometer we could explore the reasons why any differences occurred.

Attempts to provide a video record of the face of the iPhone during the testing resulted in mixed success. The after-image of previous values was often displayed behind a currently displayed value so that in a number of instances it was challenging to decide what the current value should be. For example the after-image of the number "8" behind a current value of "3" made it difficult to decide which of the two values was the current one. Slight changes in the clarity and brightness of the numeral helped in our decision but at times it was not possible to reliably make that judgment. In such instances the value contained in the 6th frame was substituted and if that failed then the value contained in the 4th frame was used. Using this methodology it was rare that a data point could not be recorded. It was expected that some error would occur in recording of these data. The question was whether this error was acceptably low.

The GoPro cameras we used had the option of using 60 fps so this is also being explored to see if the iPhone display can be made any more legible.

The "app" used to access the iPhone data in this testing was called XSensor Pro by Crossbow Technologies.

Results From Testing

In 36 of the 45 tests we obtained results that we deemed to contain an acceptable level of error (details in Table on Page 4). That error was defined as a difference between the g value obtained from the videos versus the g value obtained from the iPhone accelerometer.

As can be seen in the table on Page 4, the largest error in these tests was in Test #36 where the difference in calculated g was about 0.031 percent from a test speed of 69 km/h as was observed from the vehicle's speedometer. Assuming that the video g was absolutely correct in defining the exact start of deceleration and the exact time of stop, then the g calculated from the iPhone accelerometer would yield a speed of 66.8 km/h versus the 69 km/h speed shown on the vehicle's speedometer. Given the actual inaccuracy that may exist in the speedometer, and our ability to determine that speed by looking at the speedometer needle, and furthermore the error in determining the precise beginning of the braking, the reported error is more likely to be from these sources rather than any inaccuracy in the iPhone's accelerometer. Furthermore, the fact that we had difficulty reading the value displayed on the iPhone is another source of error that could be leading to these differences.

36 Emergency Braking Tests With Minimal Error - From February 8, 2013

Test #	Location	Test Speed (km/h)	Decel Time (Sec)	Decel (g) Calculated from Accelerometer	Decel (g) From Videos	Deviation Between Calculation Methods
1	McDonalds Parking Lot	22.0	3.30	0.194	0.189	0.005
2	EB Hamilton Rd	52.0	6.27	0.244	0.235	0.009
5	SB Veterans Mem Parkway	44.0	4.40	0.263	0.283	-0.020
6	SB Veterans Mem Parkway	57.0	8.57	0.203	0.188	0.015
7	SB Glanworth Curve	63.0	4.17	0.442	0.428	0.014
8	EB Cheapside St	45.0	6.93	0.181	0.184	-0.003
10	NB Clarke Rd	50.0	7.60	0.183	0.186	-0.003
11	NB Clarke Rd	55.0	7.70	0.188	0.202	-0.014
12	NB Clarke Rd	54.0	8.33	0.174	0.184	-0.010
13	NB Clarke Rd	67.0	10.50	0.167	0.181	-0.014
14	NB Clarke Rd	62.5	9.60	0.185	0.184	0.001
16	EB Ilderton Rd	51.0	7.30	0.191	0.198	-0.007
17	WB Ilderton Rd - Reversing	30.0	3.93	0.220	0.216	0.004
20	EB Ilderton Rd	60.0	9.17	0.168	0.185	-0.017
21	WB Ilderton Rd - Reversing	31.0	4.10	0.217	0.214	0.003
22	EB Ilderton Rd	62.0	9.37	0.191	0.187	0.004
23	EB Ilderton Rd	64.0	9.60	0.180	0.189	-0.009
24	EB Ilderton Rd	58.5	9.10	0.192	0.182	0.010
25	EB Ilderton Rd	48.0	7.17	0.172	0.190	-0.018
26	NB Poplar Hill Rd	58.0	7.47	0.212	0.220	-0.008
27	NB Poplar Hill Rd	70.0	9.90	0.205	0.200	0.005
28	NB Poplar Hill Rd	56.0	8.30	0.181	0.191	-0.010
29	EB Plover Mills Rd	60.0	9.20	0.185	0.185	0.000
31	EB Plover Mills Rd	63.0	9.27	0.181	0.192	-0.011
32	EB Plover Mills Rd	48.0	2.77	0.479	0.491	-0.012
33	EB Plover Mills Rd	48.0	4.40	0.304	0.309	-0.005
34	EB Plover Mills Rd	60.0	8.83	0.199	0.192	0.007
35	EB Plover Mills Rd	63.5	7.13	0.257	0.252	0.005
36	EB Plover Mills Rd	69.0	4.47	0.468	0.437	0.031
37	EB Plover Mills Rd	69.0	7.47	0.240	0.262	-0.022
38	EB Plover Mills Rd	67.0	10.37	0.188	0.183	0.005
41	EB Plover Mills Rd	57.5	8.17	0.209	0.199	0.010
42	EB Plover Mills Rd	60.0	8.47	0.198	0.201	-0.003
43	EB Plover Mills Rd	59.0	8.77	0.181	0.190	-0.009
44	EB Plover Mills Rd	46.0	7.20	0.188	0.181	0.007
45	EB Plover Mills Rd	50.0	7.43	0.171	0.191	-0.020

As another example, in Test #1, we conducted a slow speed test in a parking lot at only 22 km/h. The percent of g calculated from the videos was 0.194., while the value calculated from the iPhone was 0.189. Assuming that the video was absolutely correct, the iPhone value would result in a calculated speed 21.7 km/h. Again, the correlation between the two methods is quite high.

However, in 9 of the 45 braking tests there was an unacceptable level of disagreement between the two calculation methods (As shown in the table below) and we studied these more closely to determine the source of the error.

9 Braking Tests With Unacceptable Levels of Error

Test #	Location	Test Speed (km/h)	Decel Time (Sec)	Decel (% G) Calculated from Accelerometer	Decel (% G) From Videos	Difference in G	Possible Cause of Error
3	EB Hamilton Rd	52.0	3.23	0.393	0.456	0.86	Tail-light illuminates on 3rd frame after brake pedal is contacted. Normally tail-light should illuminate at 9th frame after brake pedal is contacted.
4	EB Commissioners Rd	50.0	10.50	0.172	0.135	1.28	Test conducted on substantial downgrade where vertical component of force not taken into account.
9	WB Cheapside St	43.0	7.77	0.185	0.157	1.18	Traction control was active as attempted to increase speed quickly in restricted road length to enable test.
15	SB Clarke Rd - Reversing	19.5	2.67	0.295	0.207	1.43	Reversing at low speed of 20 km/h.
18	EB Ilderton Rd	31.0	4.37	0.173	0.201	0.86	"Traction Control Active" remained displayed at time of first contact of brake pedal. Tail-light illuminates at 8 frame delay. TCA shuts off at 23 frames after initial brake pedal contact.
19	WB Ilderton Rd - Reversing	30.0	4.33	0.222	0.196	1.13	Test at 30 km/h. Tail-light illuminates 9 frames after brake pedal contact. Not able to identify anything unusual.
30	EB Plover Mills Rd	68.0	10.60	0.208	0.182	1.15	Test at 68 km/h; Brake pedal seems to move upward slightly without contact at 3 frames before being contacted. Tail-light illuminates at 9 frames after initial brake contact.
39	EB Plover Mills Rd	54.0	7.87	0.160	0.194	0.82	Test at 54 km/h. Darkness at foot pedal area makes it difficult to observe brake pedal action and its contact. Tail-light illuminates 10 frames after initial brake pedal contact. Left front tire enters area of bare pavement at 02;18;25;18 or @ 2.5 seconds before coming to a stop. Recalculation at 1 frame intervals brings Average G value to -0.181 or much closer to that calculated from video.
40	EB Plover Mills Rd	62.0	9.13	0.216	0.192	1.12	Test at 62 km/h.Tail-light illuminates 10 frames after initial brake contact. Nothing unusual detected.

In Test #3 we observed that the tail-light illuminated only 3 frames after the brake pedal was depressed. In all other tests we observed that the tail-light would illuminate 9 frames after the brake pedal was depressed. There was a clear view of the driver's foot applying the brake pedal so the source of the error was not due to our inability to determine when the brake pedal was depressed. Also we know there was no synchronization error in the videos. Low acceleration data for the first and last data points suggest that these were the source of the lower g calculation by the iPhone and this could be related to the incorrect start and stop of the test recording that coincides with the tail-light illumination anomaly. Because the test speed was only at 52 km/h and the road surface was relatively aggressive (0.456 g) there were only 22 data points on which the average g was determined so that the low data values at the beginning and end of the test had a larger effect. Therefore there was something unusual about this test that was not related to the functioning of the iPhone accelerometer.

In Test #4, the vehicle was braked on a substantial downgrade where we did not take into account that vertical force. Therefore the results are not a surprise and this does not indicate an error of the iPhone data.

In Test #9, the traction control was still active while we started to brake because we were attempting to gain speed quickly in order to be able to perform the test in a short length of road prior to making a right turn at the nearby intersection of Highbury Ave. Thus, again, this error is simply related to the actions performed in the test and not due to any error related to the iPhone accelerometer.

In Test #15, we commenced a low speed reversing action and braked at a speed of 19.5 km/h. Looking at the chart of data points we could see how a single data point (#2) was very high (0.56 g) compared to remaining 21 points which were near 0.2 g and this had the effect of raising the average. In scenarios such as this where only a few data points are available, the proper procedure would be to document the data at a more detailed level of every frame versus every 5 frames and this would reduce the effect of that single outlier. Overall one would want to be careful when conducting braking tests at such low speeds at low hertz because of the obvious potential for error. Again this would not be related to any error of the iPhone accelerometer.

In Test #18, the "Traction Control Active" information was displayed on the instrument cluster at the time that this braking test was commenced and this would have an obvious effect on the determining what forces were acting on the vehicle during the braking test. Although one would want to avoid this occurrence it is easy to activate the TC on snowy and slippery road surfaces without being aware of the fact as one would have to be looking at the instrument cluster and that is not always the primary focus of the driver when there are a large number of tests being performed in succession. Therefore this error is not associated with any malfunction or error of the iPhone accelerometer.

In Test #19 we had another situation of a low speed (30 km/h) reversing test where the first data point that was documented was 0.03 g, meaning that there was a slight positive acceleration taking place, rather than a negative acceleration. Despite this the average g calculated from the iPhone was substantially higher (0.222 g) than that obtained from the video (0.196 g). However we documented only 27 data points and in a real scenario we would want to document the data at every frame rather than every 5 frames that was used here. Although we have not had time to conduct this more detailed documentation it is reasonable to us that this is the likely cause of the disagreement.

In Test #30, we observed an unusual, small, upward movement of the brake pedal about 3 frames before it was contacted by the driver's foot. Because the tail-light illuminated 9 frames after the designated point when the driver's foot touched the pedal this gives us further assurance that we selected the correct contact time with the pedal. We also had a clear view of the pedal to determine that nothing unusual occurred except the unusual pedal motion. There was a rather large spike in the vertical and longitudinal accelerations visible in the graphic view of the face of the iPhone at about 1 second into the braking test. However this spike was not noticeable in the numerical values of the vertical and longitudinal accelerations. Given the short duration of that spike it is not believed to be the primary cause of the difference in the g averages but it is a curiosity never-the-less. At this time we have no explanation for the difference. The difference would mean that, assuming the g calculated from the video was absolutely correct and the speedometer indicated an initial speed of 68 km/h, the speed calculated from the iPhone data would be 72.8 km/h, or about 4.8 km/h higher than the speedometer speed. Although this is an observable difference it is still not a very large difference.

Test #39, represents a classic case where the rate of documenting the accelerations at 5- frame intervals clearly had an impact on the calculation of the average g. This was not expected because at an initial speed of 54 km/h, and a relatively slippery surface, we obtained 49 data points and, although not large, it is still not as small of a sample as some of the previously mentioned tests above where we had as few as 17 data points. However, using the 5-frame interval method we arrived at an average g of 0.160, which is very low, and substantially lower than the 0.194 g obtained from the video. But when we examined the data at the1-frame interval the average g rose quite dramatically to 0.181 g and very comparable to that obtained from the video of 0.194 g. This result caught us by surprise as we had conducted such examinations with other tests and did not find such a dramatic change in the calculated average g.

In Test #40 we did not find anything that could explain the differences in the two calculated averages. The test speed was 62 km/h on a tar and chip road surface that was covered in a layer of plowed and hard-packed snow. The test was conducted travelling eastbound on Plover Mills Road just after crossing into Oxford County from Middlesex County. It is possible that the iPhone average g might result in a more agreeable value if documented at a 1-frame-interval just like Test #39 however we have not had time to conduct that analysis at this time.

Figure 2: Resultant snow disbursement following braking Test #8 in deep snow.

Discussion

Up to the present time, after having used the iPhone accelerometer in several vehicle dynamics studies, we have found that its capability of sensing accelerations has produced no evidence of significant error. Much of the problems we have encountered, which are not very many, are related to issues around conducting our vehicle motions, camera set-up and retrieving the data in the most convenient and economical manner.

An important factor in obtaining good data relates to insuring that the iPhone is attached solidly to the mass of the vehicle in a central location. If this is done properly then many problems can be avoided. However this is not as easy as it would appear. Many vehicles do not have a convenient way of attaching the iPhone in the vehicle interior without causing some permanent damage to the upholstery or plastic coverings. Although the Buick Allure interior posed a challenge, we were fortunate in finding a creative way of firmly attaching the iPhone and GoPro camera to the vehicle at the centre console.

The operation of the iPhone accelerometer and retrieving its data is not ideal. All apps that we have reviewed offer the opportunity of retrieving a file of the stored acceleration data that can be sent by e-mail to a remote location such as our computer and onto an Excel spreadsheet. The file is created by starting and stopping the recording of the data but it is difficult to determine the precise timing of the start and end of the recording with respect to the roadway on which testing is performed. It has been our desire to be able to match individual accelerations precisely to specific portions of a roadway and our preliminary explorations have not resulted in a convenient way of making this connection possible using the e-mailed file option. Thus we have been exploring the ability of recording a video image of the iPhone's display. As mentioned previously this has resulted in limited success. When we review the video of the iPhone display on our video editting project the numbers appear blurred with after-image interference. This was with a recording mode of 30 fps. Recently we conducted some tests while recording at 60 fps and received a clearer image and we will be exploring that further. More recent GoPro cameras such as the GoPro3 allow recording at up to 120 fps so that might be another option to pursue. We will also be exploring changes to the brightness of the display on the iPhone to see if that makes any beneficial changes.

The process we are following is definitely more time consuming than simply uploading an already-made file of accelerations by e-mail. But the advantage of tying the iPhone accelerations to the combined videos of the grouping of cameras that we use is something valuable and we intend to pursue this approach for the time being, as our procedures evolve.

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