Good and Bad Roads Detected with Apple iPhone's Accelerometer and Gyros

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One might not consider that the nuisance device that drivers use to distract themselves on the highway could also be used as a tool to uncover how a collision occurred. We are not discussing some cryptic data storage that spies on the iPhone owner. Instead we refer to the iPhone's accelerometer and gyros that are used to tell the phone how it is being moved and positioned in space so that it can display a proper image on its screen. Various applications ("Apps") are available that allow the user to gain access to the phone's accelerometer and gyros, and the data can either be watched live on its screen or stored onto a file that can be e-mailed to other locations such as the user's computer.

The accelerometer has been available on older models of the phone. The reported resolution of the accelerometer is about 0.018 g which is more than sufficient for almost any accident reconstruction project. But with the introduction of the iPhone 4S in 2011 the phone also became equipped with a tri-axis gyro which reportedly increased the phone's ability to accurately report its position and motion.

As an example, the XSensor app by Crossbow Inertial Systems provides the user with the ability to send a file that can be imported into an excel spreadsheet. The data can be captured at either 4, 16 or 32 samples per second. It can report data from four separate screens: Mags, Accels, GPS and Gyros.

The Gyros screen provides very detailed information about the iPhone position as well as the rate of its rotation along its three axes (x, y and z), as shown in the photo below.

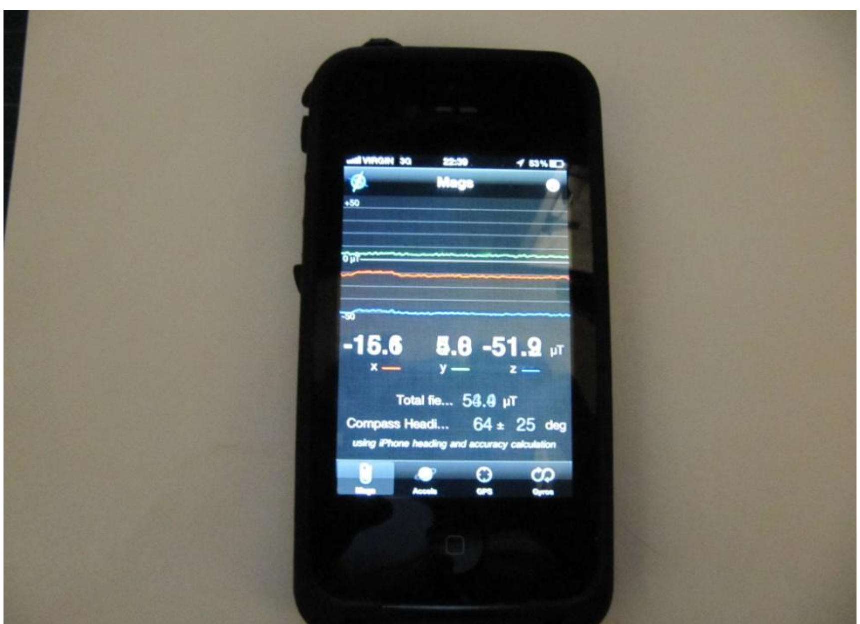


Figure 1: The XSensor app display on the Apple iPhone 4S

Figure 2: View of Gyros screen of the XSensor app.

The bottom row of numbers (roll, pitch and yaw) identify the present position of the iPhone with respect to its predefined axes. We are experimenting with the phone's placement however we found a solid position on our vehicle's centre console, with the screen facing upward and the top pointing to the right. There is a Society of Automotive Engineers (SAE) practice that defines the positions of axes with respect to a vehicle and we are exploring how that convention fits with the XSensor terminology. It appears that our current placement of the phone results in the mis-naming of the axes on the screen. However, the more important matter for our testing is to attain a secure position of the phone so that it is solidly anchored to the vehicle structure. The fact that the axes are mis-named, may be confusing but this is of secondary importance. For now we can say that, when placed in the above-noted position, the X-axis of the iPhone is a line that passes through the centre of a vehicle from front to rear thus rotation about this line would involve the rolling of the vehicle, for example, if the left side were to drop while the right were to rise. Thus the "pitch" variable is the one that signifies roll in this orientation of the phone. Similarly, the Y-axis is a line that passes across from left to right such that rotation about this axis would cause the front/rear of the vehicle to "rise" or "fall" and this is the "roll" variable. Finally the Z-axis is a vertical line passing through the centre of the vehicle such that rotation would occur if one were to turn a steering wheel sharply and cause a fish-tailing or yawing motion. This is the "yaw" variable displayed on the screen. Therefore each value along the bottom row of the Gyro display informs the viewer about the extent of the phone's (and vehicle's) rotation with respect to each axis.

The top row of values (x, y and z) provides an indication of how quickly the present position of the iPhone is changing in degrees per second. In the present orientation the "x" value indicates how quickly the vehicle is moving side-to-side, the "y" value indicates how the ends of the vehicle "rise" or "fall" with respect to its centre-of-gravity and the "z" value indicates how quickly the vehicle is changing its pointing angle. All this detailed information can be helpful when a reconstructionist wants to study what road features might have contributed forces on a vehicle, such as in a scenario where a driver has lost directional control of a vehicle and crashed.

To demonstrate the capabilities of the iPhone we anchored it securely to the centre of a test vehicle and drove through an S-curve of a rural roadway. Before providing the results of these tests the following photos will provide some information about the site where the testing was performed.

Figure 3: Looking north from several hundred metres south of the S-Curve.

Figure 4: Northbound view, while travelling on the downgrade toward the S-Curve.

Figure 5: Northbound view, just prior to reaching the location of a manhole cover just south of the S-Curve.

Figure 6: Note the yellow, curve-warning sign on the right roadside as we climb the small knoll just before reaching the manhole cover.

Figure 7: We began our data collection just before the test vehicle travelled over top of a manhole cover in the northbound lane. The manhole cover just begins to come into view in the foreground as the S-Curve reveals itself in the background.

Figure 8: The manhole cover becomes more visible toward the right portion of the northbound lane in the foreground.

Figure 9: The manhole cover is now clearly visible on the right portion of the northbound lane as we see further details of the S-Curve in the background.

Figure 10: As we pass the manhole cover we can see the first portion of the S-Curve which is a curve to the right.

Figure 11: As we approach the right curve portion of the S-Curve we begin to see the opposing left curve begin to emerge in the view in the distant background.

Figure 12: Upon entering the right curve we can now see the short distance of straight roadway before the commencement of the left curve in background.

Figure 13: As we pass through the right curve we notice the elevation change as the left curve disappears from view because it is located in a sag of the road.

Figure 14: The elevation change and sag in the road is evidenced as we travel further into the right curve while the left curve completely disappears from view.

Figure 15: As we approach the end of the right curve we enter into a short segment of roadway that is straight and relatively level before entering the left curve.

Figure 16: As we pass through the short, straight section of the road the left curve begins to come into view in the background.

Figure 17: As we approach the left curve we note the elevation drop as we cannot see the surface of the road ahead.

Figure 18: As we enter the left curve its surface begins to be revealed and we note that this curve is sharper (i.e. has a smaller radius) than the preceding right curve.

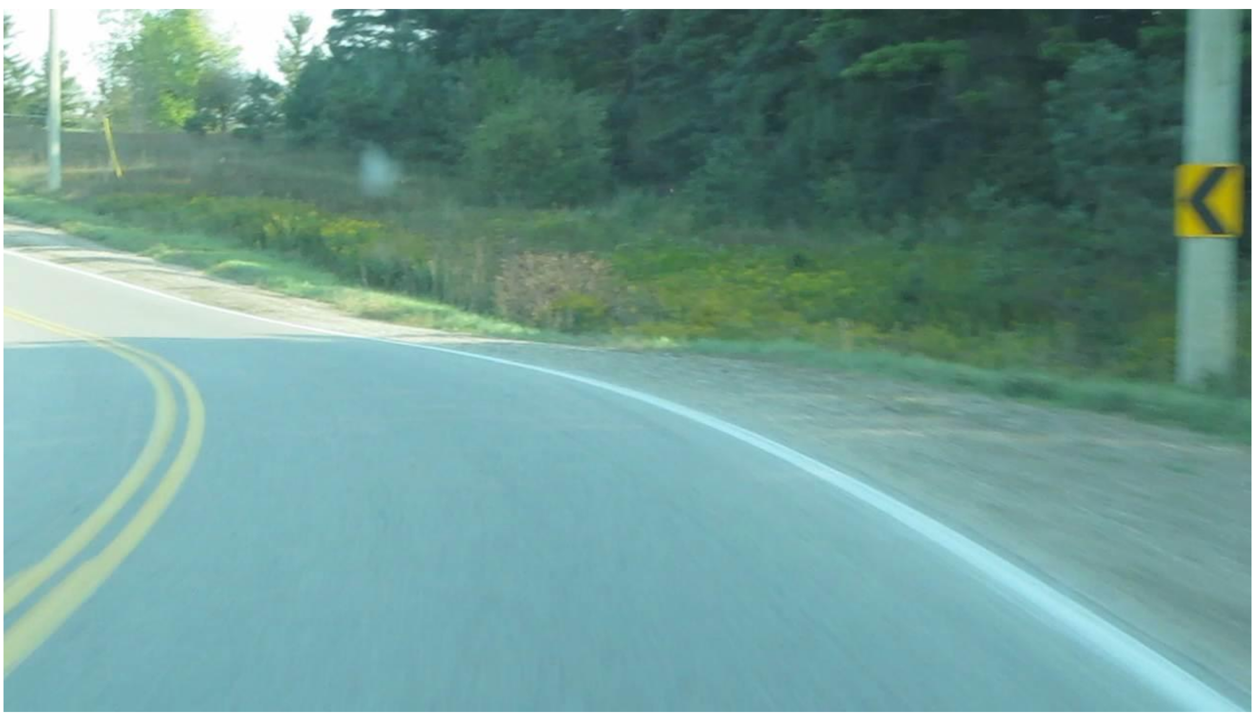


Figure 19: As we continue through the left curve we appreciate the severity of its change in direction.

Figure 20: As we approach the latter part of the left curve we see that the straight road ahead contains an upgrade.

Figure 21: As we drive out of the left curve we see how the straight road ahead contains an upgrade and this is where our data collection was stopped.

Figure 22: To complete our description of the S-Curve this photo shows a southbound view just north of the S-Curve, so we are now looking in the opposite direction from all the previous photos.

Now that we have provided a detailed pictorial view of the S-Curve we can examine what the iPhone was able to provide in terms of details of the forces applied to it, and the test vehicle.

The Chart on Page 15 shows values of the longitudinal (blue line) and the lateral (orange line) acceleration documented by the iPhone as the vehicle passed through the noted S-Curve. The vehicle's cruise control was set at 70 km/h throughout this test.

Note that when the test vehicle passed over the manhole cover the iPhone registered relatively high accelerations that were both lateral and longitudinal. In particular, the blue line indicates a high longitudinal acceleration approaching 0.3 g. Such a result could explain how a driver might lose control of a vehicle while passing over such a disturbance.

As the vehicle passes through the right curve we see a relatively moderate level of lateral acceleration (red line) that stays generally above -0.1 g with some small deviations approaching -0.2 g. This curve contained a warning sign which advised drivers to select a maximum speed of 60 km/h while passing through the curve. The selection of the 60 km/h advisory should be based on testing such that the lateral acceleration should not achieve an absolute value greater than 0.15 g. Since we were travelling at a speed that was 10 km/h above the advised speed it would seem reasonable that travelling at the advised speed would reduce the values shown in our chart to values below -0.15 g. Therefore the speed advisory was likely correct for this right curve.

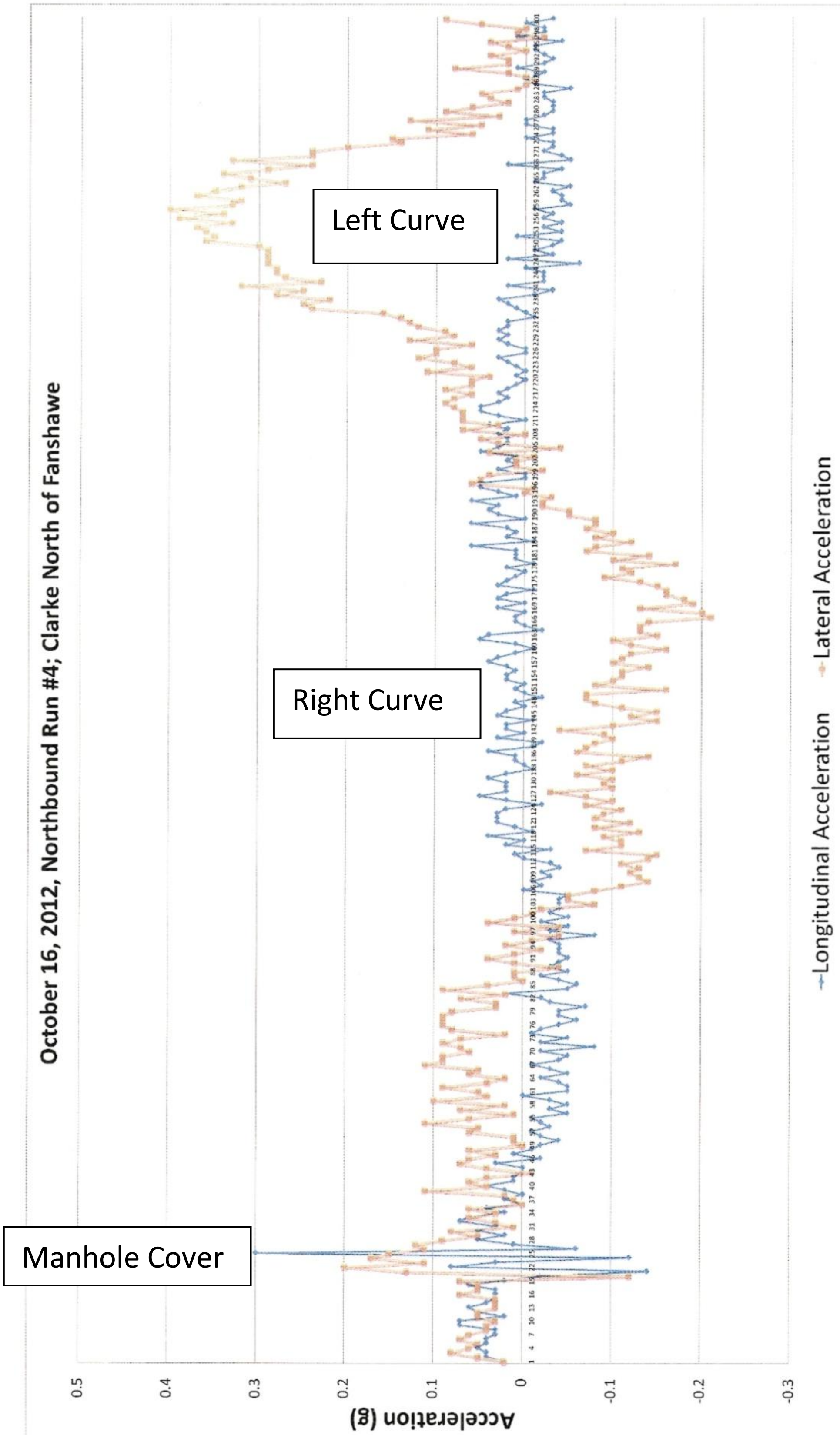
However, as we examine the results for the left curve the appropriateness of the advisory speed comes into question. Note how the lateral acceleration (red line) reaches values of 0.4 g. This is much higher than the recommended 0.15 g. Even if we reduced the speed of our test vehicle by 10 km/h, thus bringing it match the 60 km/h speed advisory, it is highly unlikely that the lateral acceleration would drop to the degree that would fall in the range of 0.15 g. Thus this is an example where test results using the iPhone can help to establish that the signing of a curve may be inappropriate.

The speed advisory sign could have been adjusted to provide a lower advised speed of 50 km/h or less. However, if one examines the details of North American guidelines for roadway geometry there are prohibitions for advising changes in speed greater than 20 km/h which might require the municipality to re-build a road, and this would be a costly consequence. For example, since this road has a posted maximum speed of 80 km/h, a sign bearing an advisory speed of 40 or 50 km/h could trigger an immediate red flag to an independent inspector who was familiar with roadway geometry guidelines. However, by maintaining the speed advisory at 60 km/h it would be more difficult to detect the inappropriate signage because one would have to conduct an objective test by driving through the curve equipped with an accelerometer before evidence was obtained that the signage was inappropriate. When a municipality has a number of roads that need to be adjusted to match North American guidelines and insufficient funds are provided to the roads department by elected officials to make those adjustments creative actions to mask non-compliance can take place.

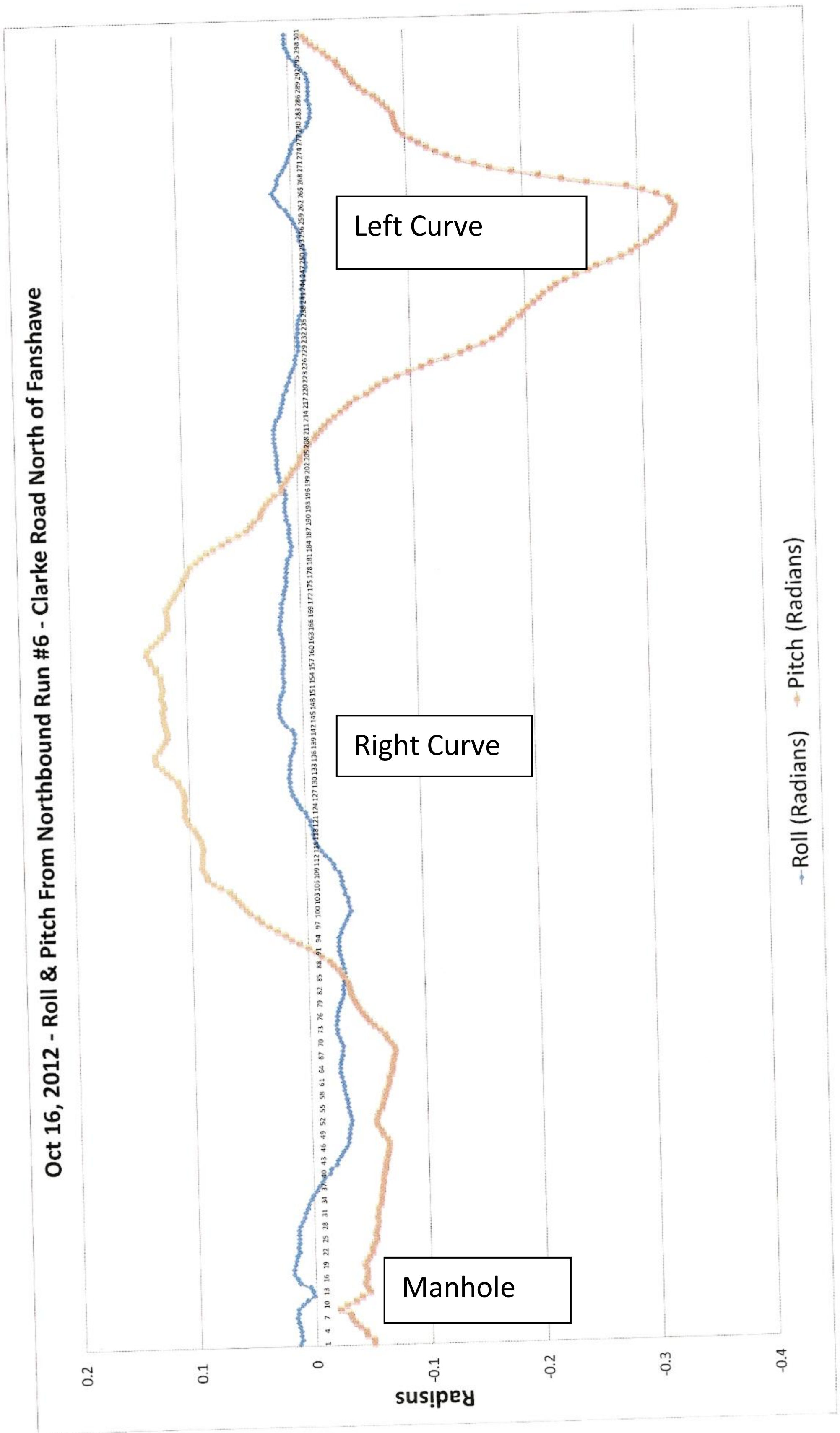
An alternative could be to reduce the posted maximum speed to 60 or 70 km/h and thus allowing for a speed advisory sign to be placed with an advised speed of 50 to 60 km/h. However, we have documented that the average speed of vehicles passing through the tight left curve is in the range of 74 to 78 km/h, and it is highly likely that the average speed on approach to that curve is even higher. Thus the practical reality is that, despite the posting of a lower maximum speed drivers will likely ignore that prohibition and continue to drive well above that reduced maximum speed. Without continual police enforcement, which has its own associated cost, the problem will continue to exist until the curve is finally re-built. Without the benefit of being able to provide an objective test with the iPhone's accelerometer/gyros the source of such a problem might never be uncovered.

The iPhone would appear to provide reliable results from the few tests we have conducted with it. However placement of the iPhone within a test vehicle must be secure, solid and convenient to the operator and this may require that the iPhone be oriented in a manner causing the display to report a mis-named axis. For example, in the present orientation of the iPhone the Xsensor app appears to have confused the "roll" with the "pitch" values in the Gyros display. The graph on Page 16 shows the roll (blue line) and pitch (red line) for the same location as the previous chart. Note that, as the test vehicle is rounding the two curves (right and then left) of the S-Curve one would expect a large amount of roll of the test vehicle from side-to-side with little pitch. Instead the chart shows the opposite. While travelling through each curve it is the pitch variable which shows signs typical of what we would expect of the roll variable, and vise versa. This may be a programming error in the XSensor app or an orientation issue with the iPhone. Regardless, the iPhone itself is likely capturing the data reasonably accurately and we are not being misled by the meaning of the data from the individual axes. Additional testing will determine where the problem truly lies, how important it is for us to maintain the current orientation of the iPhone and how confusing the explanation of the results may be.

In summary, the Apple iPhone contains interesting features such as an accelerometer and gyros that make it a useful tool in the reconstruction of motor vehicle accidents. Its price is very reasonable considering its primary function is to operate as a mobile telephone. Perhaps it has also extended itself to be a mini computer with its ability to access the internet as well as perform a number of other functions made accessible by its extended applications. Its portability makes it an additional benefit to the accident reconstructionist as it is small enough and will likely always be carried by the owner so that when unexpected events arise the ability to study the road forces will likely always be there so long as a test vehicle is also available. It still needs further testing to compare its functions to more traditional accelerometer hardware used in accident reconstruction such as the Racelogic V-Box or Vericom VC4000.



October 16, 2012, Northbound Run #4; Clarke North of Fanshawe
Acceleration (g)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
Left Curve
Right Curve
Manhole Cover
Longitudinal Acceleration
Lateral Acceleration


Oct 16, 2012 - Roll & Pitch From Northbound Run #6 - Clarke Road North of Fanshawe
Left Curve
Right Curve
Manhole
Radians
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
Roll (Radians)
Pitch (Radians)

Gorski Consulting
London, Ontario, Canada