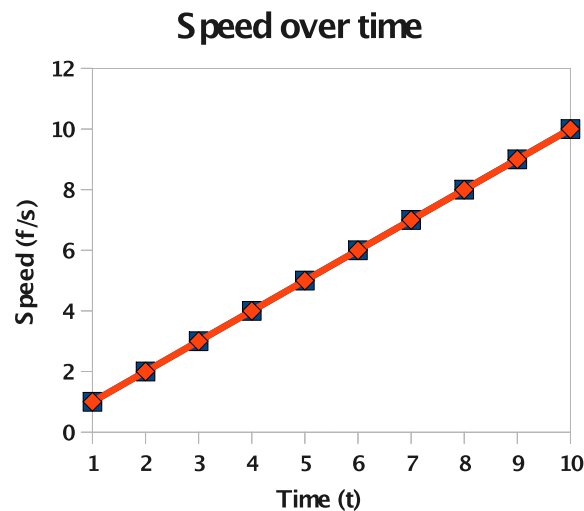


Chris Garner

Forward Acceleration

Forward acceleration is easy to quantify and understand. Forward acceleration is simply the rate of change in speed. In car terms, the quicker the car accelerates, the quicker the speedometer moves. People in the car can also feel the acceleration push them back into the seat, or into the seatbelt for deceleration.

Let's say a car's speed accelerating from a stoplight can be measured with the formula $y(t)=x$ where $y(t)$ is the cars speed over a period of time (t). Realistically, we could gather this data by recording speed at regular intervals of time. A second person in the car could act as a recorder, and at every second, they record the speed. Those points can be graphed, then write an equation for the line the points made.



The acceleration can be measured by calculating the slope of the line, rise over run, which happens to be 1/1 or simply 1. This is calculated by figuring how far up (rise) the line goes for a certain distance over (run). We could also have take the entire graph and said that the slope is 10/10, a fraction that will also reduce to 1. Unfortunately, real world acceleration rarely follows a linear path. Calculus addresses more complex formulas for calculating speed.

$$y' = x \left(\frac{dx}{dt} \right) \gg y' = 1$$

As you can see, $y' = 1 = \text{slope}$.

I have not been including units in any of the equations. Only using units, the equations would look like,

$$y = \text{feet/second}$$

$y' = \text{feet/ (second}^2\text{)}$, another “per second” was added when the derivative was taken according to time (t).

We can see by the equations above that speed is measured in feet/second, acceleration in feet/ second². Additionally, we could integrate the formula for speed to get, $y(t) = (x^2)/2$. The units of this equation are in feet, and the equation produces the number of feet traveled over a given period of time (t). In a real life situation, distances could be marked on the pavement, and times recorded when the car reaches each mark, each time / distance pair can be graphed, and assigned a formula for the line the graph produces.

Lateral Acceleration

Lateral acceleration is a little more complicated because it happens in two dimensional space rather than one dimension. Though more difficult to measure, lateral acceleration is the force that throws car passengers sideways during a turn. Acceleration around a uniform circle is denoted by

$$a=v^2 / R$$
¹

or acceleration is equal to the velocity squared, divided by the radius of the circle. The common unit for lateral acceleration is the “g force”. To calculate g's, divide the recorded acceleration by the gravitational acceleration. If the recorded acceleration is 32.2 ft/s², divide by gravitational acceleration, also 32.2 ft/s². The result is 1, without any units, but is labeled “g force”. This number is expected because the 1g is the force felt by the acceleration due to gravity. The Nissan GT-R is one of the highest performance production cars on the lateral g skid pad. The GT-R pulls .96 g before losing traction.² That number is what we will try to achieve with our vehicle during the tests using the car with the mounted. Hitting that number will be more than challenging, but the tests will show how close we get.

Calculating speed from acceleration

As we saw above, the formulas for distance, speed, and acceleration are all connected. In a situation with constant acceleration, such as 1 ft/s² from above, the velocity can be found with this equation.

$$V= v_0 + at$$

Velocity is equal to the initial velocity plus acceleration times time. Unfortunately, this rarely represents real life. When constant acceleration is not the case, calculus must be used to relate velocity and acceleration as seen below.

$$V= V_0 + \int_0^t a dt$$

The velocity is equal to the initial velocity plus the integral from 0 to time t of the acceleration. In the case that the acceleration is constant, the result is the same as the formula listed above this one, but this equation has the power to address acceleration as a constant or a function of time.³

1 p. 99 Physics Textbook

2 <http://www.insideline.com/nissan/gt-r/2009/full-test-2009-nissan-gt-r.html>

3 p. 67

The Experiment

I will use the CBC to record acceleration readings. These readings will be imported into Excel to be graphed and assigned an equation to represent the points. I will use the acceleration data to calculate the final speed of the vehicle.

I will also attempt to have the CBC display the current speed calculated from the accelerometer in real time. The processing power of the CBC may become a factor in the accuracy of this test.

Finally, I will use the CBC to measure the lateral g's while the test vehicle does cornering and turning maneuvers.

Experiment 1

The test vehicle will perform a 0-60-0. The car will begin the test completely stopped, accelerate to 60 mph, then return to a stop. This type of event is common to test a car's acceleration and braking. The data from the CBC will show the car accelerating, small deceleration during gear shifts, and one large deceleration while braking. After completion of the experiment I will

1. Attempt to calculate the top speed.
 1. The experiment will be considered a success if that number is $\pm 5\%$ of the actual top speed. (Acceptable range, 57-63 mph)
2. Calculate the max g force while accelerating and decelerating.
3. Calculate the time to complete a gear shift
 1. Time will be calculated from when acceleration becomes 0, through the deceleration, and stop when 0 acceleration occurs.

Experiment 2

The test vehicle will again perform a 0-60-0. The CBC code will treat each instantaneous acceleration reading as linear so that no integration will need to be performed. Mathematically, the results will be completely accurate as the times between readings approaches 0, and less accurate as those times approach infinity. The benchmark for recording data without any processing for speed is 52 reads per second, plenty quick enough for "accurate" results. The code while processing to calculate speed has yet to be benchmarked.

During the experiment, the driver will call out speeds at intervals of 10 mph. The passenger will compare that reading to the display on the CBC. The experiment will be considered a success if the CBC readings are $\pm 5\%$ of the car's speedometer readings. Because of the possibility of rapid acceleration, the passenger will have a paper with a list of speed ranges, if the recording CBC is within the acceptable tolerance, that entry will receive a mark on the list. The only result this test will show is with in or not with in tolerance, not exactly how accurate the reading may be. This experiment will

1. In real time calculate the speed of the test vehicle with $\pm 5\%$ tolerance.

Experiment 3

This experiment is designed to monitor the lateral g forces during a turn. I anticipate the forces peaking just before losing traction. This experiment is pretty simple. Have fun and see how well the car works.

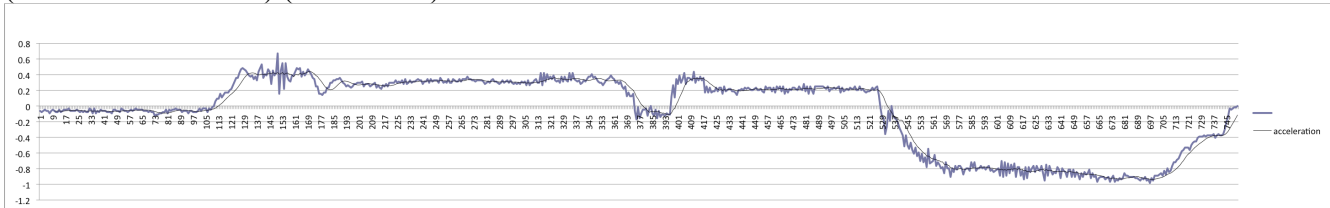
Results

Experiment 1

1.1

I assumed that each axis of the accelerometer would record on the same scale. A reading of 64 on the z axis, would be the same on any other axis rotated to feel gravity. I began by averaging the readings on the z axis. 64.00 was the magic number. Dividing the acceleration of gravity by the average reading produced a number that I could divide all of the readings by to put them into feet/ second² (1.9875). Once I had the acceleration readings, I removed the extra data from before and after the 0-60. I used the equation $V=V_0+at$. Treating each reading as constant acceleration I transformed the formula to $V=\Sigma a * t$ or the sum of the accelerations multiplied by the time interval for each read. To change the velocity from feet/sec to mph multiply by 3600/5280.

$$(7144/1.9875 * .021) (3600/5280) = 51.5$$



1.2

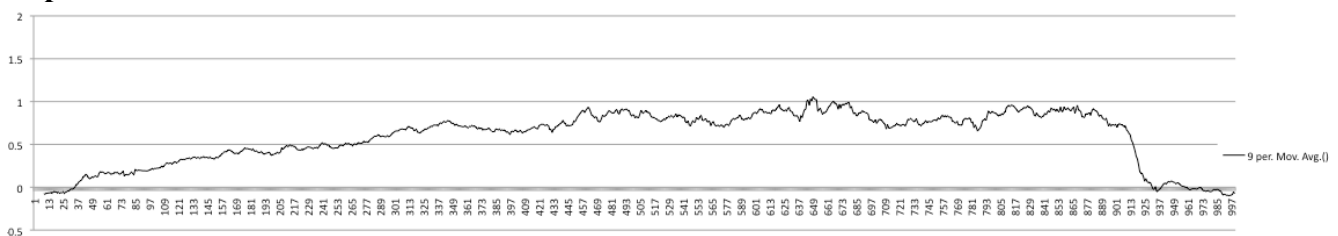
Max g force was easy to calculate. The highest positive g was .67g at reading #150.

1.3

Experiment 2

Real time speed calculation resulted in a disaster. This test suffered from two restrictions. The processing power of the CBC lacked the needed speed to perform accurate calculations. The math behind treating acceleration values as constants relies on a value t that is very small, the more the CBC has to compute, the longer it takes between readings and the larger t becomes. Another contributor to the slow processor was the need to process print statements to the screen. Additionally, errors are carried forward. With the CBC stationary, the “Current speed” approached 1,000 feet/ second rather quickly. Without the CBC completely level, the horizontal axis began to feel the acceleration of gravity, which quickly got out of hand. Without completing the vehicle test I declared this test failed. More accurate computing requires a quicker processor. With an abundance of processing power, the ability to do vector analysis to determine how much gravitational acceleration the horizontal axis feels becomes a real possibility for producing accurate results.

Experiment 3



The graph represents a moving average of the data retrieved from a lateral g test. The car drove a tight circle. As you can see, the car eased into the turn, lost traction at reads 349, 469, and 673. The car straightens out of the turn at 913. As I mentioned before, reaching 1 lateral g is a very significant feat.

According to the CBC, we passed that number near the 650 mark. The test vehicle has aftermarket tires, springs, shocks, and sway bars. The numbers aren't far from what I expected given the test vehicle, but are slightly higher than I expected though still in the reasonable range.

Final Thoughts

We had a great time using the integrated accelerometer to track the vehicle. With additional processing power, I believe that vector analysis to counter the effects of a CBC that does not remain perfectly flat will produce more accurate results. On a practical note, losing traction may look cool, but slows the car down.

All tests were conducted in a closed environment.

Random After Thoughts

The program I wrote for the CBC to log the accelerometer readings can record at 48 readings per second. To put this in perspective, a standard video records at somewhere around 30 frames per second. With this recording rate we can see shifts points during acceleration and losses of traction during a turn. The CBC records the accelerometer readings on an arbitrary scale, to bring these numbers to a useful scale, I laid the CBC on a level surface, one where only the Z axis showed a value, dividing the value by 32.2 fps/s, creates a unit less number that I divide the readings by to provide readings in the English standard unit of feet per second/ second.

Acceleration occurs in three dimensional space- forwards and backwards, Side to side, and up and down. The CBC measures each direction of acceleration and graphs them. The GUI will graph positive and negative acceleration of one plane as a function of time, though multiple graphs can be overlaid. Because of the force of gravity, the Z plane will have a value other than 0, while the CBC is at rest. The X and Y planes will read 0 while the CBC is at rest. Additionally, with basic calculus we can derive that the rate of change in speed is acceleration. The accelerometer, measuring acceleration will tell us how quickly or slowly the speed of the CBC is changing. More importantly, when the CBC is mounted inside of a vehicle, we can measure the force that the vehicle accelerates, decelerates, and how much lateral force a vehicle can withstand during a turn.