



## Data Acquisition using Smart Phone Applications

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### Abstract

There are numerous publically available smart phone applications designed to track the speed and position of the user. By accessing the phones built in GPS receivers, these applications record the position over time of the phone and report the record on the phone itself, and typically on the application's website. These applications range in cost from free to a few dollars, with some, that advertise greater functionality, costing significantly higher. This paper examines the reliability of the data reported through these applications, and the potential for these applications to be useful in certain conditions where monitoring and recording vehicle or pedestrian movement is needed. To analyze the reliability of the applications, three of the more popular and widely used tracking programs were downloaded to three different smart phones to represent a good spectrum of operating platforms. Several tests were conducted to evaluate the applications ability to measure speed, elevation change, and positioning on aerial imagery. The data reported by the applications in each test was compared to a Race Logic VBOX VB20SL3 Data Acquisition Unit that was also used in the same tests. The VBOX unit was used as a standard against which to measure the applications efficacy since this unit is specifically designed to monitor and record vehicle movement<sup>1</sup>. The results show that under certain conditions, speed, positioning on aerial imagery, and elevation change as recorded by applications were relatively accurate for conditions where the recorded period occurred over a long duration of time. The results from this testing shows that recording the motion of a vehicle or pedestrian over a long duration of time, greater than 10 seconds, with minimal changes in velocity can be properly documented by the use of a smart phone running a commonly available applications.

### Introduction

Monitoring a vehicles speed and recording the path of travel are parameters that can be integral in analyzing an accident or the time-space relationship between vehicles or pedestrians. Technologies

such as photogrammetry or specially designed units such as the Race Logic VBOX are widely accepted and utilized tools for determining these parameters. The complication implementing this technology or using bulky equipment can be costly, cumbersome, and in some cases unnecessarily robust depending on what data actually needs to be collected. Using a smart phone to determine speed, elevation change, and position data could be useful in situations where the level of detail offered by other devices or technology is not needed. The smart phone could also help in situations where carrying equipment to a testing area is difficult. Below is a list of the types of situations where collecting speed, elevation change, and position data using only a phone might be particularly useful.

1. Water sports such as boating or waterskiing, where waterproofing and smaller equipment would be more useful. Determining speed and position through photogrammetry techniques may be difficult too, without visual references to track position.
2. Snow and ice sports such as skiing, ice skating or snowboarding. For similar reasons as regular water sports, not to mention the difficulty in hauling the equipment to certain remote areas. Trees and the changing terrain may also prevent constant observation and video recording or other means to track position and speed.
3. Simple speed analyses, like determining the maximum speed on a hill on a bike or a typical left turn in an intersection where a high sample rate or extensive equipment is overkill.

In any of these situations the ability to collect data without the need for extensive analysis like photogrammetry or expensive or bulky equipment used in data acquisition units would be helpful. This paper examines the use of the smart phone to accurately collect speed, elevation change, position, and the various conditions that affect the accuracy and reliability of using these programs.

## Overview

The phones that were used in this test were the following:

1. Apple's iPhone 6 running Apple 9.0.2
2. Motorola's Droid Maxx running Android 4.4.4
3. Samsung's Galaxy S5, running Android 5.0

Each of these phones comes equipped with a radio frequency (RF) chip that support Wi-Fi, GPS, voice, and data communications and at least one accelerometer. The RF chips in each of the phones tested were made by Qualcomm but each had a different model number. The Samsung Galaxy S5 contained a WTR1625L, the Motorola Droid Maxx contained the MDM6600 Dual-Mode, and the Apple iPhone 6 had the QFE1000 along with the MDM9625M2,3,4. The iPhone contained two accelerometers manufactured by Bosch, as report by ifixit who disassembled the phone. However, all the tracking applications we researched relied primarily on the GPS for position. The maximum sample rate that phone GPS receivers would record was 1 Hz. We were informed of this through multiple sources including the designers of the applications themselves, and was primarily to save battery life on the phone and because for most apps, 1 Hz was sufficient resolution. The accelerometers were not used by the applications unless there was no GPS signal available. In cases with insufficient GPS signal, the accelerometer was used to estimate speed through a comparison to a data base of similar accelerometer patterns. Therefore, the accelerometer was actually not calculating speed directly, but rather matching a pattern of acceleration that, when compared to the database, would suggest an average running speed<sup>5</sup>. Surprisingly this estimate seemed fairly accurate.

Each of the applications in addition to recording speed, and position, also recorded elevation change. This was reported in feet, rounded to the nearest foot, and sometimes shown graphically. Prior to deciding on the three applications that were to be tested, 10-15 applications were first vetted. Several reasons precluded some of the applications from being further considered, though there are certainly more than the three presented in this paper that would have qualified. Applications that did not run on multiple platforms such as the Apple IOS, and the Android IOS were eliminated, since part of the evaluation was to determine whether different phone operating systems affected the accuracy of the application. Also eliminated were applications that were shown to have a limit to the maximum speed they could record. For instance, some tracking applications geared towards running and walking would stop recording data if the speed of the phone was reporting a speed faster than humanly possible. Also, if the application did not report the test run graphically on the internet, it was excluded from the research since the process of evaluating the accuracy relied on using the graphical outputs shown online by the applications.

The following three applications were eventually used because they were available on each phone system, were relatively cheap, and output the resulting data in a graphical fashion that allowed the data to be converted to an excel file for use in analysis.

1. Strava - GPS Run and Ride Tracker
2. MapMyFitness - GPS Workout Trainer
3. Runtastic Road Bike Pro - GPS Cycling Computer

One variable in this study that wasn't specifically validated is the internal clock of the smart phones. The time on the phones, used to determine speed, appeared to be consistent between each other, and without a better standard against which to measure the accuracy, the clocks were assumed to be accurate. It also seemed reasonable to assume that the phone engineers have established a reliable digital clock.

## Procedure and Test Setup

In order to evaluate how the applications perform under a variety of situations, three testing scenarios were established. In general the differences between the scenarios is related to the typical travel speeds of slow, moderate and fast. The three scenarios involved the following modes of mobility, listed from slowest to fastest.

1. Rollerblades
2. Bicycle
3. Motorcycle

In all, three modes of movement were tracked by three phones running three applications for a total of 27 data sets that were compared to 3 benchmark data sets obtained from the VBOX VB20SL3 during each of the three mobility tests.

For each of these scenarios, a backpack unit was carried by the operator. This unit included all the phones that were being tested, as well as the benchmarking VBOX unit. [Figure 1](#) is a photograph of the backpack unit used in each of the tests, along with the phones and VBOX unit.



[Figure 1. Backpack rig with smart phones and VBOX unit](#)

Each of the scenarios was run through the same roadway course that included hills, stop lights, trees in some areas, and curves. This variety provided a better opportunity to assess the mapping ability of each application, i.e. how closely the application tracked the movement around curves and hills on the aerial map that the motion is recorded on. [Figure 2](#) shows an aerial image of the roadway used for the testing with notations added for the start and end of the scenarios. This area was digitally mapped using a Sokkia Set530R3 Reflectorless Laser Total Station and a Faro Focus 3D X330 Laser Scanner, so that both the elevation changes and the position in the roadway, as recorded in the applications, could be evaluated. Start



Position A is where the motorcycle run started, and the bicycle and rollerblade runs started at Position B. The ending position was the same for all three runs.

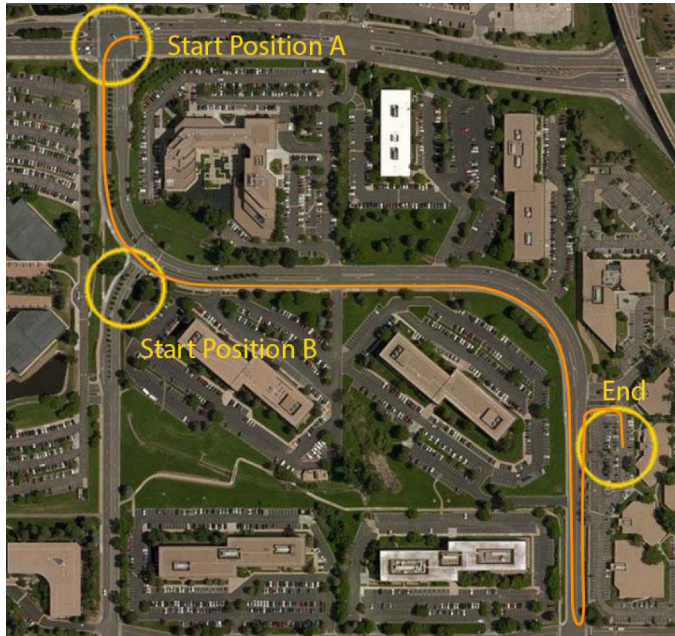


Figure 2. Aerial showing travel path of testing, two different starts positions are noted

After collecting the data on the apps for each scenario, the recorded run could be accessed online. The online record showed speed and time and a graphical representation of the elevation change. Depending on the application, the speed was reported as miles per hour (mph) or as a pace, such as minutes per mile. The path of travel recorded was also included, and for each of the applications tested, this was shown as a path on an aerial image. Each application's online graphical record was maximized in the view of the monitor, screen captured, and then processed so the graphical data could be digitized numerically into an excel file. Figure 3 shows an example screen shot from the MapMyFitness application. In this figure, the aerial image contains the mapped path in red, and along the graphical chart is speed in blue and elevation change is represented in gray, with a red outline.

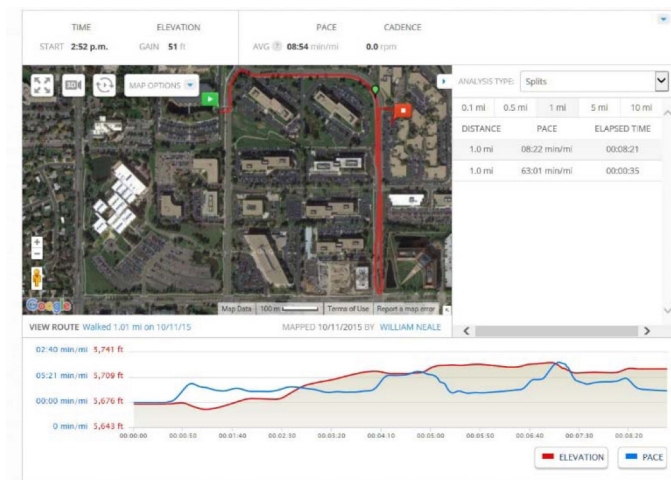


Figure 3. Sample screen grab from MapMyFitness record of the Rollerblade run

Once each graph was screen captured at the highest resolution available for the monitor, both axes were converted into a common unit of measurement for all the applications (speed in MPH, and time in seconds). Each image was loaded into 3D animation software, such as 3DS Max, and traced along the X and Y axes. This tracing process recreates the slope of the line within the maximum and minimum values dictated by the captured graph. Each sampled point along the newly created 3D line is then reassigned its corresponding speed and time value, and plotted into usable numerical data such as an excel file.

The excel files from each of the runs from the phones were compared directly to the exported VBOX data. For comparing the elevation change, and path or travel visually represented on the aerial imagery, data points from the web screen captured was compared to the survey and scanning data that was collected of the entire route.

## VBOX

The VBOXII SX- Triple Antenna (SL3) data logger was used for the standard to which the applications would be measured against. The VBOX is an industry accepted data acquisition system that has been widely accepted in the accident reconstruction community for measuring GPS locations, speed, acceleration in all 3 axis, yaw, pitch, and roll angles, heading, and elevation changes. The accuracy of the VBOX is listed on the Racelogic website, and the unit is calibrated once per year to insure its accuracy. The calibration sheet received by Racelogic shows an accuracy in the recorded speed of +/- 0.06 mph. In the testing performed for this paper the use of one antenna was utilized for the VBOX because the yaw, pitch and roll angles were not a measurement that was to be compared.

## Speed and Position Tests

Prior to beginning any of the scenarios, the backpack unit was equipped with all the phones and the VBOX unit, and harnessed on to the user. Since the applications can run simultaneously with each other, all three applications on each phone were triggered to begin tracking the "workout" and the VBOX unit was likewise initiated. Figure 4 shows the setup of the backpack unit that was utilized for the bicycle and rollerblading scenarios.

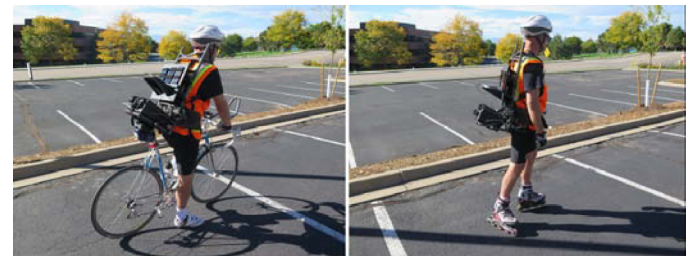


Figure 4. Setup photographs of the bicycle and rollerblade runs

For the bicycling and rollerblading scenarios, the same path of travel was used, which essentially involved starting at a traffic signal and travelling approximately 1 mile, both up and down hill, and around a curve. Video was also taken during the testing. Figure 5 shows a still frame from the bicycling scenario. The lateral path of the bicycle and rollerblades was as close to the center of the travel lane as possible.



Figure 5. Video still frame from the bicycle run with interval cones

For the motorcycle scenario, an additional area was tested that included an intersection, with a left turn maneuver. This was added to evaluate the tracking ability of the applications to determine the position and speed through a turn at an intersection, starting from a stop. This scenario was added since determining the change in speed, and position through the turn, would typically take extensive equipment or analysis, despite a seemingly simple maneuver. Situations such as this, where the maneuver should be simple enough to record without expensive equipment is included to see whether the phone would provide a suitable device for capturing this motion. Figure 6 shows the setup of the backpack unit on the motorcycle. Like the bicycle and rollerblade path, the motorcycle maintained the center of the lane of travel as close as possible.



Figure 6. Setup photograph of the motorcycle run

## Results of the GPS tracking

After accessing the online graphics and arials for each application, excel files were created by processing the graphs into numerical data. Figure 7 shows a sample of this data. The graph in Figure 7 shows velocity in the Y axis and time in the X axis. This graph can then be directly compared to the results of the VBOX data collection, as shown in Figure 8. The data between all the scenarios is synced by doing a fit of the patterns showing a change in velocity, since the exact start and end times of the applications varies slightly. As can be seen in Figure 8, there is general agreement between the velocity tracked by the phone applications and the velocity tracked by the VBOX unit except for the sections where the movement was at or near 0 mph.

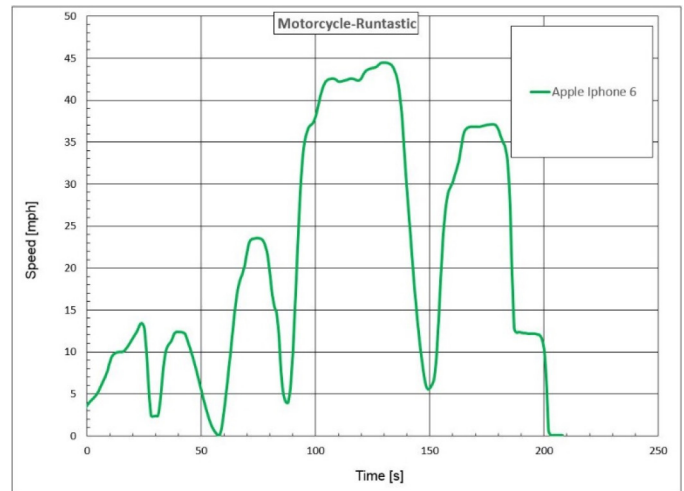


Figure 7. Motorcycle run with the Runtastic Application running on an iPhone

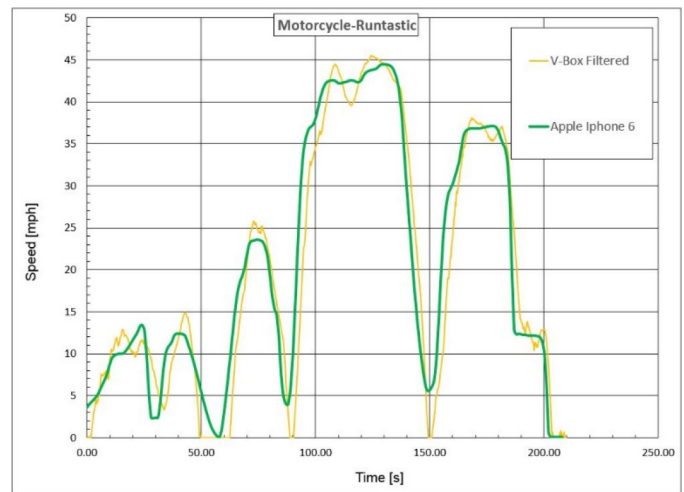


Figure 8. Graph from above figure compared to VBOX

## Velocity Tracking

In evaluating the accuracy of the applications ability to measure velocity, a broad range of speeds were measured. The basic tests involved the three different modes of mobility, i.e. rollerblade, bike, and motorcycle. To help evaluate different speeds within each of the means of mobility, all three tests were subjected to velocity changes through the course of each run. In other words, stop signs, signal lights and slopes up and down that affect speed were all part of the terrain over which the tests were run. This helps explain why the graphs in Figure 7 and 8 show several changes of increasing and decreasing velocities. The change in velocity for the rollerblading ranged from 0 to 18 mph, the bike ranged from 0 to 25 mph and for the motorcycle the range was 0 to 45 mph. The maximum speeds reported by the VBOX and the rollerblade test runs is shown in Table 1, bicycle test in Table 2, and motorcycle test in Table 3.

By using all three modes of mobility, each with a corresponding high end speed, a full range of speeds over similar distances could be evaluated. The period of total time for the rollerblading run was approximately 480 seconds, the bicycle was approximately 275 seconds and the motorcycle was approximately 200 seconds. The total distance for the motorcycle test was approximately 6,100 feet, and the total distance for the bicycle and rollerblade test were approximately 1 mile. The % error in the max speed for each



application and each phone was calculated and found to be less than 6%, with the Runtastic application having the lowest average error of max speed for all runs calculated to be 2.5% and the Droid Maxx having an average error of 3.8%.

Table 1. Maximum speeds reported from the rollerblade test

Rollerblade - Maximum Reported Speed [mph]			
(V-Box Maximum Reported Speed = 18.4 mph)			
Application	Droid	Galaxy	IPhone
Map My Fitness	17.3	17.3	18.1
Runtastic	17.6	17.7	17.5
Strava	17.2	17.0	17.2

Table 2. Maximum speeds reported from the bicycle test

Bicycle - Maximum Reported Speed [mph]			
(V-Box Maximum Reported Speed = 24.5 mph)			
Application	Droid	Galaxy	IPhone
Map My Fitness	24.0	24.2	24.8
Runtastic	24.5	24.0	23.6
Strava	24.3	23.8	24.0

Table 3. Maximum speeds reported from the motorcycle test

Motorcycle - Maximum Reported Speed [mph]			
(V-Box Maximum Reported Speed = 45.5 mph)			
Application	Droid	Galaxy	IPhone
Map My Fitness	51.9	51.8	48.9
Runtastic	45.3	45.0	44.4
Strava	45.6	45.0	46.2

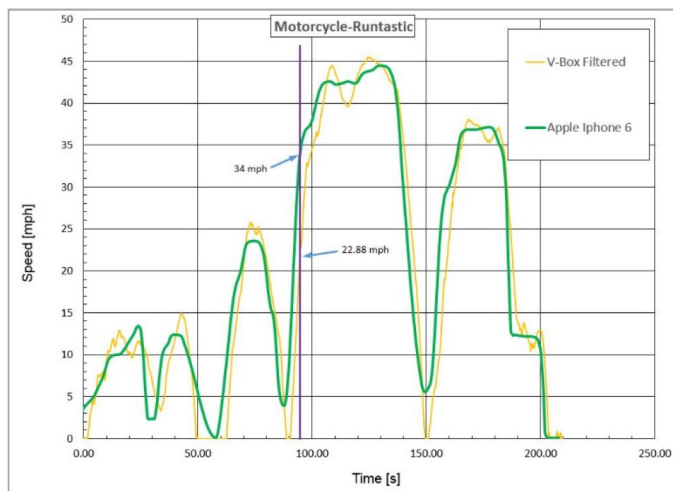


Figure 9. Sample of velocity at 95 seconds

Review of the results shows that the trend of the velocity measured by the applications followed generally well with the VBOX data however there were significant discrepancies when measured at discrete points. In other words, the plot of the velocity graphs for all the applications in all three runs trended well with the VBOX but if a

specific point in time was chosen to compare the data, the differences could be significant. For example, a measurement taken at 95 seconds in the motorcycle run with the Runtastic application running on an iPhone would show a speed of 34 mph while the VBOX would report a speed of 22.88 mph showing an error of 48.8%. To help illustrate this, the graph in Figure 9 and 10 shows a vertical purple line drawn at 95 seconds and corresponding intersection of the VBOX plot and Runtastic application.

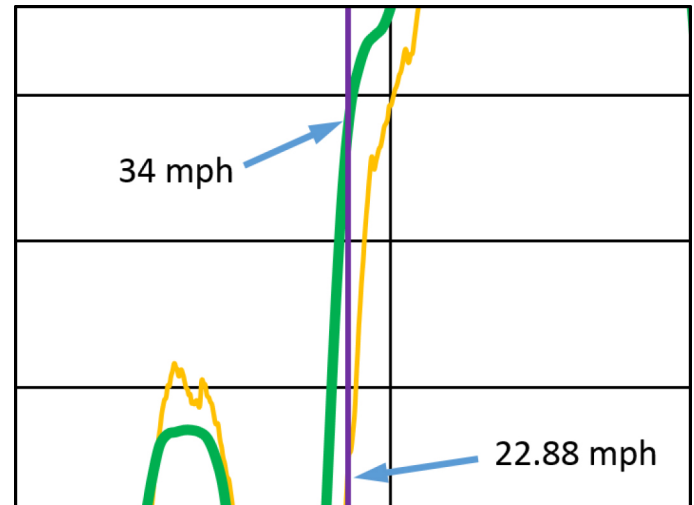


Figure 10. Close-up image of the speed taken at 95 seconds

Although the measurement taken at a specific point could result in significant error, what we did find was that when the velocity comparison was tracked over a longer segment of time, the data was relatively reliable. The reason for the error measured in the above example was due to how quickly the velocity changed, which did not give the applications enough time to sample the velocity and also the internal smoothing performed by the applications software. For example, if you were to measure the acceleration of a motorcycle while traveling at 15 mph to 35 mph in 2 seconds, the application would have only taken, at most, 2 data points. The 2 data points could have been taken at any time during the acceleration, such that a data sample could be missed that would otherwise show a much greater alignment to the VBOX. The VBOX had a higher sample rate of 20Hz compared to the applications of 1Hz. The resulting effect is the lack of enough specific measurements taken to give you a discrete velocity for a short time frame (1 to 2 seconds), but enough data points to give the general trend of speed, and maximum speed if these velocities occurred over a sufficient duration to have several data samples. Measuring velocity at a discrete point in time during an acceleration phase is not very reliable for shorter durations of 10 seconds or less because of the 1Hz sample rate. For longer time frames of 30 seconds or more, however, there is general agreement between the tracked velocities of the smart phones comparable to the VBOX (within a few miles per hour). To explore this, further examination was performed on the bicycle run. In Figure 11 the graph shows 7 points which were examined to calculate the slope between each point.

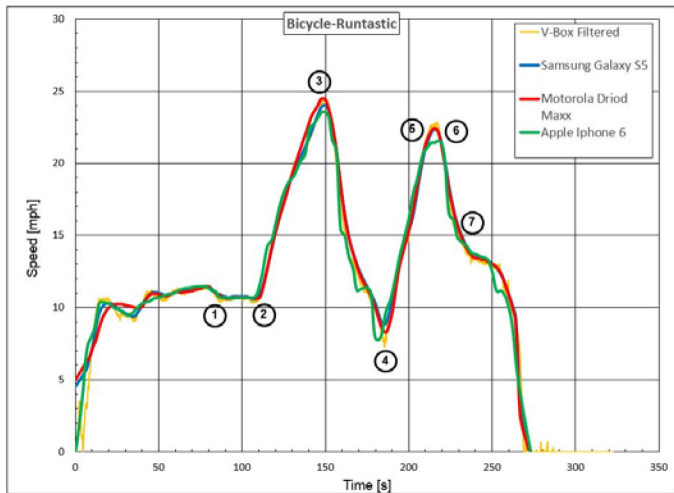


Figure 11. Bicycle run with Runtastic illustrated with 7 sampled points

In this example from the bicycle run, the average time between points ranged from 5 seconds to 42 seconds. Comparing the slopes of the lines, which is the acceleration or deceleration, shows that the data fits relatively well. For example taking the data from points 2 to 3 shows that the average acceleration between the applications and the VBOX were relatively close. The results are shown in Table 4.

Table 4. Acceleration between points 2 and 3 for the bicycle using Runtastic

Point 2 - Point 3	
Acceleration ( $\Delta\text{speed}/\Delta\text{time}$ ) [g]	
V-Box	0.015
Droid	0.015
Galaxy	0.014
Iphone	0.013

The same can be said when the velocity stays relatively constant over a longer period of time as seen between points 1 and 2 as shown in Table 5.

Table 5. Velocity at Point 1 and Point 2 on the bicycle run using Runtastic

Point 1		
Data System	Time [s]	Speed [mph]
V-Box	89.1	10.57
Droid	87	10.79
Galaxy	87	10.86
Iphone	89	10.69

Point 2		
Data System	Time [s]	Speed [mph]
V-Box	104.9	10.58
Droid	105	10.68
Galaxy	104	10.69
Iphone	103	10.69

We also evaluated the velocity recorded during the rollerblading test. When aligning the rollerblade test's velocity, shown in Figure 12, the fit between the VBOX data to the phone application's data was not as close as in the bicycle test's alignment, as shown in Figure 11. The lack of alignment in the rollerblade test's velocity data is likely due to the left to right motion required when rollerblading to maintain speed. The small movement from left to right adds additional lateral distance

which can introduce error between the VBOX and the phone applications which are not as sensitive as the VBOX in recording the lateral movement. The lateral movement also happens relatively quickly, within 1 to 2 seconds, which is insufficient time for the applications sample rate. Despite this, the slopes between the peaks and valleys are again a reasonably good fit. Figure 12 shows the data collected from all 3 smart phones operating the Runtastic application compared to the VBOX. As was done previously in the bicycle test, the slope was calculated between 4 sets of points.

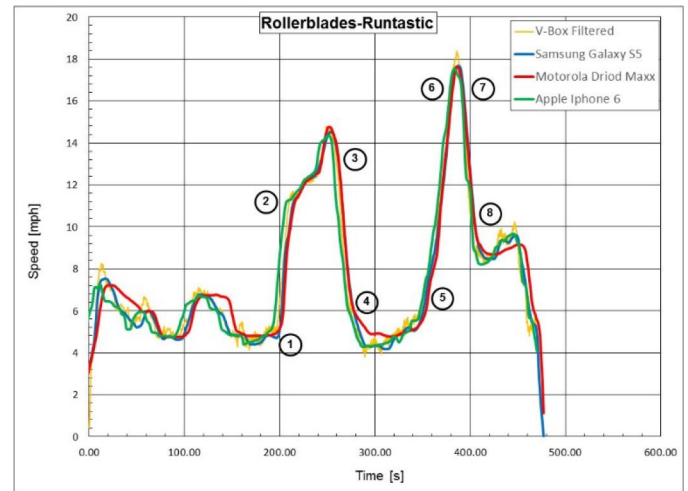


Figure 12. Rollerblade run with Runtastic illustrated with 8 sampled points

Once again the slope of the line between points was a reasonable fit when compared to the VBOX data. As shown in Table 6, the deceleration between points 3 and 4 are relatively close to the deceleration measured by the VBOX.

Table 6. Acceleration between points 3 and 4 for the rollerblade run using Runtastic

Point 3 - Point 4	
Acceleration ( $\Delta\text{speed}/\Delta\text{time}$ ) [g]	
V-Box	-0.023
Droid	-0.023
Galaxy	-0.021
Iphone	-0.020

What we found was that if the data is sampled over a long enough period of time where the application and phone can sample enough data, the velocity is relatively accurate. Or, given a sample of relative constant velocity over a period of 10 seconds yields relatively accurate results even at a discrete point. Error arises when a specific velocity measurement is made in a region of data where the velocity change occurs too quickly, not allowing the applications sufficient time to sample the data. This error was present in time steps of a few seconds and less.

Another common source of error for every application tested occurred when the movement was at or very near 0 mph. Some of the applications are designed to give the user a pace, reported as speed in minutes per mile. If the application is designed this way, and the user is stopped, it appears that the application does not register this speed. Though it is unknown exactly why the applications have trouble reporting a zero speed, it is suspected that this problem is related to

the computation problem associated with including zero in the average pace. If a person is stopped and the speed is zero, the pace, reported in minute miles would be infinite. This problem of reporting zero speed can be seen in the motorcycle test, where the pace reported by the application at the beginning of the run is approximately 5 mph (see Figure 13). In all of our testing, the user was stopped for a period of time prior to moving to allow for the applications to begin recording. Clearly at the beginning of the data, the velocity recorded as zero is inaccurate.

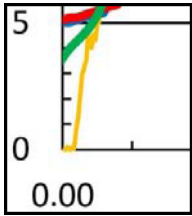


Figure 13. Initial speed reported by the apps compared to the VBOX which is labeled in Yellow

The applications tended to work well for speeds where there is a longer distance with relatively small changes in speed over longer time periods of 30 seconds or more. In sections where the time was 30 seconds or longer, without significant changes in velocity, the reported speeds were within 1 to 2 miles per hour of the VBOX reported speeds. The areas where the velocity reporting was less accurate, up to 11 mph, occurred when the acceleration was too rapid or the phone was stationary.

## Elevation Change and Aerial Tracking

Since the smart phone applications also recorded elevation data, and mapped the path of travel on an aerial as part of the record output viewable online, the accuracy of both of these sets of data were evaluated. For elevation data, the reported positions from the phones applications were compared to surveyed points of the same locations along the roadway obtained using a Sokkia Laser Total Station. For the path of travel, the aerial overlaid images available in the reports online for each application and each run were scaled and the offset from the tracked path as it was represented graphically, was measured against the actual known path of travel, i.e. centered in the right lane of travel.

For the purpose of this paper the elevations measured from the total station and the VBOX are not a representation of the absolute (actual) elevation but are used for a comparison of the data. The analysis of the data was performed by looking at the relative change in elevation within each recording device. The data reported in the graphical figures in this paper reports the elevation recorded by each respective recording device/app and is merely used as a reference, not the actual elevation relative to sea level. In general, the applications collected elevation data reasonably well (within 3' to 4' when compared to commensurate surveyed points) in areas with more gradual slopes. Sharp slopes and low points in the roadway where both trees and buildings were present, likely made accurate reading from GPS more difficult and were consistently inaccurate. In these areas the elevation data were off by as much as 10' to 20' in elevation. Another pattern that emerged was that the applications tended to measure each scenario (rollerblading, cycling and motorcycle riding) internally consistent, but with large offsets between the applications. In other

words, any one application, for all three scenarios, reported similar elevation points for each run. But when the points from one application were compared to a set of elevation points from another application, even though the general shape of the data points was similar there could be a significant offset of over 15' in elevation. It was concluded that an application is consistently measuring elevation regardless of the speed it's traveling, or manner of mobility, but that the absolute elevation point its recording can differ from other applications by over 15 feet. The Figures 14, 15, 16 show the comparison of the applications recorded elevation points to survey points. It is not known why one applications would have an absolute elevation number that differed so much from another application's record of the same location along the run.

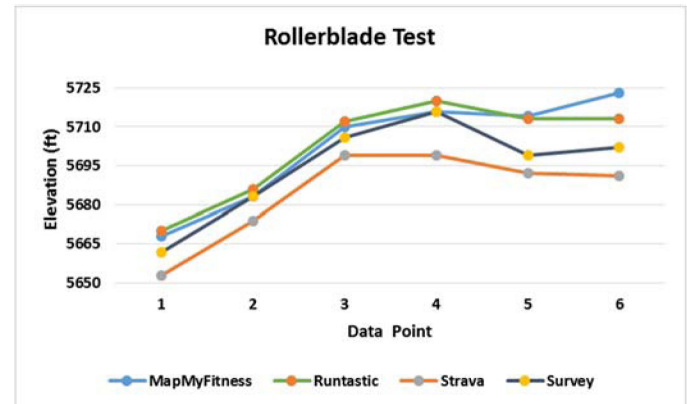


Figure 14. Comparison of elevation data points-rollerblade test

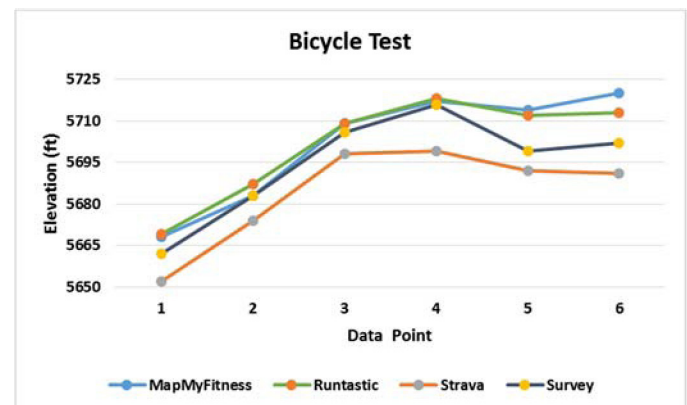


Figure 15. Comparison of elevation data points-bicycle test

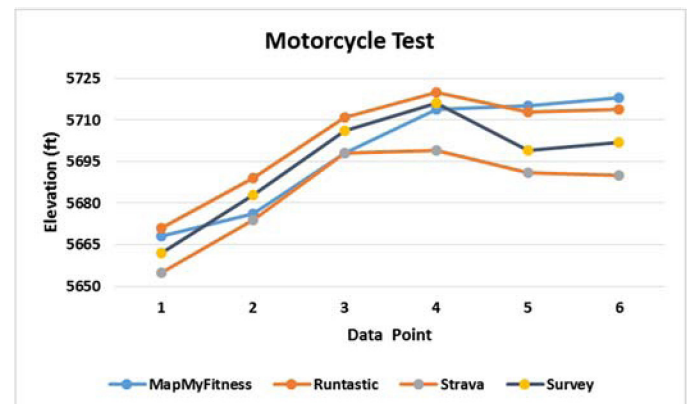


Figure 16. Comparison of elevation data points-motorcycle test



The tracked and graphically mapped paths of travel for the applications were represented on an aerial that was screen captured from the internet, and scaled in AutoCAD to measure its position laterally and longitudinally. In general, the longitudinal tracking was reasonably accurate though laterally, the position represented on the aerial at times was very close to the actual position (within 1 to 2 feet) but at other times grossly off (as much as 40 feet). The only observable pattern was that the tracking appeared more accurate for lower speeds of travel. For speeds less than 10 mph, the tracking was fairly accurate, but with speeds 30 mph or more, the lateral position could shift so that it represented the path of travel as if going into oncoming lanes, or into the front grass areas of neighboring property. Shown in [Figure 17](#) is the most accurately shown aerial overlay, from the Runtastic application of the lowest speed test, the rollerblades. [Figure 18](#) is also a map from the rollerblade test from a different application, MapMyFitness. In this overlay, the area that shows inaccurate results happens to be in a low lying area, surrounded by buildings and trees which probably made it difficult to obtain a good GPS signal. This has been circled in orange. In these areas the path of travel, as represented on the aerial, was in error as much as 12-15 feet laterally. For the higher speed tests, the motorcycle runs, [Figure 19](#), also from MapMyFitness has been included to show the aerial overlay. Visible in this view is one section of this overlay that shows the degree to which the lateral tracking is represented inaccurately. The path in this figure shows a lateral position almost 40' off of the known path (also shown with an orange circle). It should be noted that the path of travel recorded and mapped on an aerial by the VBOX showed about perfect alignment with the known path at all speeds and through all modes of travel.



Figure 18. MapMyFitness GPS mapping from the Rollerblade test

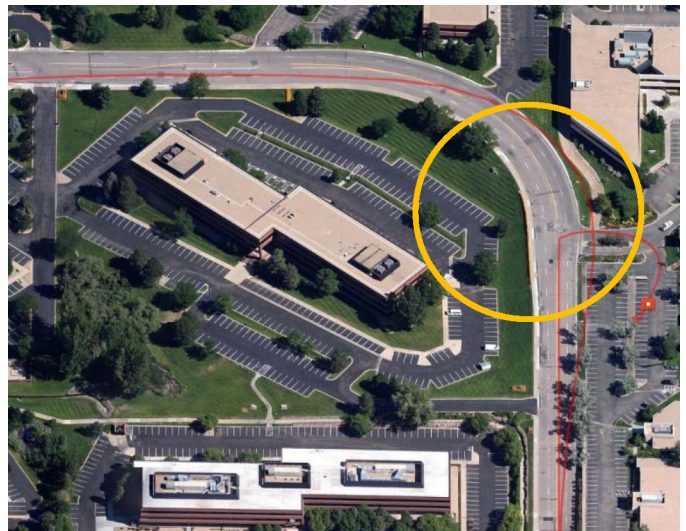


Figure 19. MapMyFitness GPS mapping from the Motorcycle test



Figure 17. Runtastic GPS mapping from the Rollerblade test

## Conclusions

Only three applications were tested though there are numerous other application available that would likely perform the same, assuming they meet similar basic criteria. The primary factors determining the accuracy of the applications in recording speed, position, elevation change is the data sample rate of the application, and the level of detail of the graphical output available online. Therefore, if other applications are being researched for usability not discussed in this paper, it is important to determine what the actual sample rate is and if the graphical representation of speed and time is reporting points with the expected sample rate. It would also be worthwhile to check that the graphical output on the aerial can also be zoomed to increase resolution.



For the three applications tested, each tracked velocity, elevation and position reasonably well, though with some common circumstances that can cause significant error. In testing velocity, these errors include measuring velocity when the phones was stationery. Also, error occurred when the change in velocity was rapid, since the sample rate of 1Hz could not create enough data points to properly show that change. When the phone begins moving from a start, has a relatively low accelerations or decelerations, or a constant velocity, the tracking performed well. For recording elevation change, the applications performed well at representing the relative slope, regardless of speed, though the absolute elevation was different for each of the applications. When mapping the path of travel, slower speeds, around 10mph would track well, though speeds above 30mph could show a dramatically different travel path than was actually traveled, particularly in curves, and in low lying areas where trees and buildings may disrupt satellite signals.

Since not all applications were tested and reported in this paper, a bullet list of findings and recommendations has been included below, for future applications and for other applications that might be appealing but not directly tested here:

1. Not all the applications work the same. Some applications record at different sample rates, some applications have a maximum speed (such as some running apps) where the tracking stops if the speed is beyond what a human could possibly run. Some applications do not present the tracked run online and therefore limit the reporting of the run to viewing on the smart phone. Look for applications that have online access, where the recording is posted for either download or for higher resolution viewing. These applications typically have good graphs showing the speed, distance, and elevation change. Some even had exportable file formats. The online display of the data allows the cursor to move across the graph while showing the actual data points collected, thereby revealing what the sample rate is.
2. The applications usually do not report a speed of 0 mph, since this would likely be a mathematical problem when the application calculates a pace. Consider the effect of any tests that require the movement of a vehicle to be stopped.
3. Some applications have preset modes, where the run being recorded can be considered “biking” “jogging” or “walking” for instance. Choosing these presets prior to recording can affect the sample rate that the program relies on to record speed. Where possible, choosing a preset that maximizes the sample rate is preferable.
4. While examining these applications, we found that recently, devices had become available that increase the maximum sample rate of the phone to up to 10Hz. Using these devices would likely greatly increase the accuracy of the phone tracking abilities.

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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. The process requires a minimum of three (3) reviews by industry experts.

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