GPS Accuracy

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Topic

As an avid cyclist I want to find out the best way to record my training sessions, this includes information about the distance travelled during a session. This data is used to analyse improvements in performance and adjust my training program. The purpose of this experiment is to find out how accurate a device that uses a GPS to measure distance will be. It is likely that the GPS measuring device will ‘under’ measure distance. This could be due to the device taking "data points" on its current location, and when the device travels around a corner the GPS software interpretation of the data points will assume you did not take the full corner. To fix this problem the software does a process called smoothing where it interprets the data points and attempts to create straighter lines and rounded corners. So far no other research has been commenced into finding how inaccurate a GPS device is and the difference between different devices.

Literature Research

Questions

The literature review raised a number of questions in regards to what other factors might influence the measurement of distance by a GPS device.

- Does the weather affect the performance of a GPS device?
- How does the availability of satellites affect the performance of a GPS device?
- Are there differences in devices in measuring distance with a GPS?
- Is there an effect of using different clocks in the GPS and the satellite on GPS accuracy?
- Does the position of the satellites relative to each other affect the GPS accuracy?
- How does the software ‘smoothing’ process (Kalman filter) influence the measurement of distance from one point to another?

Answers

One of the major points raised in the literature surrounding inaccuracies of GPS measurement is weather [3] [2]. The weather includes not only local weather but space and terrestrial weather. It has been shown that water vapour and rain can block or delay GPS signals, thus having a negative impact on accuracy.

Other factors that can affect the accuracy of GPS measurement is the number of available satellites for the GPS device to ‘lock’ onto [1]. If there aren’t enough available satellites in the sky then the device won’t work. Satellites can be blocked by physical objects including buildings and trees. The signal can also be reduced or blocked underwater, indoors or underground. There is software available which tests how many satellites the GPS device is using to gain its positioning accuracy.

The device accuracy may also be affected by the GPS receiver. One of the devices commonly used in bike training is a Garmin GPS device. The literature reports that the standard Garmin is accurate to within 15 metres [14]. However newer Garmin GPS receivers use a ‘Wide Area Augmentation System’ to improve accuracy to 3 metres. The type of receiver could influence the data point marking and in turn affect the software ‘smoothing’.

Receiver clocks in the GPS device are less accurate than atomic clocks which are used in satellites. Receiver clocks are a lot cheaper than atomic clocks. The literature discussed that although the difference may only be one millisecond, this error equates to about 300 kilometres[15]. This is an important factor for any data point smoothing software to take into account.

There is an ideal satellite geometry where satellites are spaced evenly with wide angles in relation to the GPS receiver. This delivers the most accurate positioning. Satellite 'geometry/shading' is when the satellites are in a line or a tight group [14]. If this occurs then the accuracy of the GPS can be affected.

The software used by GPS devices must take into account a large number of variables. The most common algorithm reported in the literature used to smooth data is the Kalman filter [9]. This filter smooths the irregular data points allowing corners to be more rounded [10] [11]. It also allows problems found from inaccurate or erratic data points to be fixed causing straighter lines [12]. When the data has been smoothed the inaccuracies should mainly be found in corners being shorter or 'cut' altogether resulting in a shorter distance being measured than the actual distance travelled.

Therefore my question is as stated: does a measuring device that uses a GPS to measure distance always measure short? After much literature research it appears as if a GPS will under measure in all circumstances. However no physical testing has been reported in the research to test different GPS devices. This project will undertake the physical testing of different GPS devices comparing them to a traditional speedometer, which uses wheel rotation to measure distance.

Hypothesis

The hypothesis being tested in this project is based on knowledge that a GPS data point is interpreted by software and a 'smoothing' algorithm is applied. The assumption is that 'a GPS measuring device will always measure distances shorter than the actual distance because of the process in which data points are interpreted'.

Thus the hypothesis is:
A device that uses a GPS to measure the distance travelled will always measure shorter than the actual distance due to the process in which data points are interpreted

Aim

To discover the inaccuracy of distances travelled when measured by a device which uses a GPS to measure distance.

Variables

The Independent variable in this experiment is the device which is measuring the distance. The dependant variable is the distance travelled.

Independent variable: Measuring device

Dependant Variable: Distance

Controlled variables:

- The courses where distance is measured (location, number of corners, hills, etc). To eliminate this variable three different courses shall be recorded.

- Weather both space [2] and terrestrial [3], as water vapour and rain block GPS signals. Holding tests at the same time of day and weather will negate this problem.
- A correctly calibrated speedometer to find a base line distance measure.
- The GPS's frequency of data points measured [5].
- GPS accuracy (no GPS lock) [4].
- The amount of usable satellites in range of the GPS device [1].
- Speed being travelled as this will spread out the data points.
- The GPS software's interpretation of data points [5].
- Vibration, as this affects the internal wiring scrambling the GPS receiver therefore all courses will be of reasonable surface quality.
- Temperature, as all tests are run at the same time of day the temperature will not differ.

Method

1) Acquire several devices that use a GPS to measure distance, a singular device that measures distance by the rotation of a wheel and a bicycle to travel the distance. Attach all devices to the bicycle making sure that they are all fitted to move the same distance. Correctly calibrate the device that will use the rotation of the bicycles wheel to measure distance as this will be the control.
2) Ride the bicycle recording data for three different courses. Course one shall be straight, course two shall have corners and straight sections whereas course three shall be a circular route. All devices shall measure and process each course ridden. Each course shall be ridden 3 times for adequate data and repetition.
3) All data shall be processed, logging all distances and analysed for any unequal measurement.

Courses

Three courses will be used throughout the testing. All of these routes have their own requirement (straight, hills and corners or circular course). Below are maps of the three courses.

Course 1

Course one is a flat straight course. The route that has been chosen is a 1.5 kilometre section of the old Pacific Highway at Raleigh. An aerial view of the course is shown with the start at point A and finish at point B.

Course 2

The second course must have hills, straights and cornered section. This couse is located on Central Bucca Road, Bucca. It is an undualting course, approximately 5.7 kilometres in length, with both tight and slight corners, as well a several straight sections. A picture of the course is shown on the right.

Course 3

Course three needs to be a constant corner, making a velodrome the ideal candidate. The velodrome selected is located inToormina and is 333 metres in length. Six laps of the course will be recorded as one of the three mandatory repetitions, alllowing each repetiton to be approximately 2 kilometres.

Devices

Several devices will be used during these tests. All devices except the control will use a GPS to record their distance. Also, each devices will use different software to interpret the GPS data. The devices and software are listed below.

Device 1

A Garmin edge 500 cycling computer will be used as the first GPS device. The data from this device will be processed by Garmin connect [5].

Device 2

The second device is a Sony Xperia-T Android phone. This device will process the data points through the software Strava [6].

Device 3

The third device is a Samsung Galaxy Nexus Android phone, using Google My Tracks[7] software.

Device 4

Device four is a Samsung Galaxy S3 Android phone using the app Map My Ride[8].

Risk Analysis

This experiment was carried out using a road bike. There are inherent risks in riding bikes on the road which include cars and the conditions of the road. Risk management strategies included

- Wearing a helmet.
- Riding with another adult rider to be visible to traffic.
- Riding during quiet periods e.g. Sunday morning.
- Selecting courses with low volumes of traffic.
- Conducting the experiment on a sunny day with good light and dry road conditions.

Results

Course 1

The first course is a straight flat route that will measure the GPS accuracy without other factors such as corners and hills. This course is 1.5 kilometres in length and will be repeated three times.

Device	Repetition 1	Repetition 2	Repetition 3
Device 1	1.51km	1.49km	1.51km
Device 2	1.60km	1.50km	1.60km
Device 3	1.57km	1.57km	1.54km
Device 4	1.52km	1.55km	1.53km
Control	1.50km	1.50km	1.50km

Results from Device 1

Repetition 1

Repetition 1 is nearly a perfect picture. Although you cannot see it in this satellite image above, the start is about 10 metres out from the actual start.

Repetition 2

Although this line appears perfect, the measured distance was less than the actual distance.

Repetition 3

This follows the trend set by the other repetitions using this device, the line appears perfect but in this case the distance measured is longer than the actual distance.

Results from Device 2

Repetition 1

This picture does not have any major deviations but still measured long.

Repetition 2

This picture shows a perfect result as we can see in the results.

Repetition 3

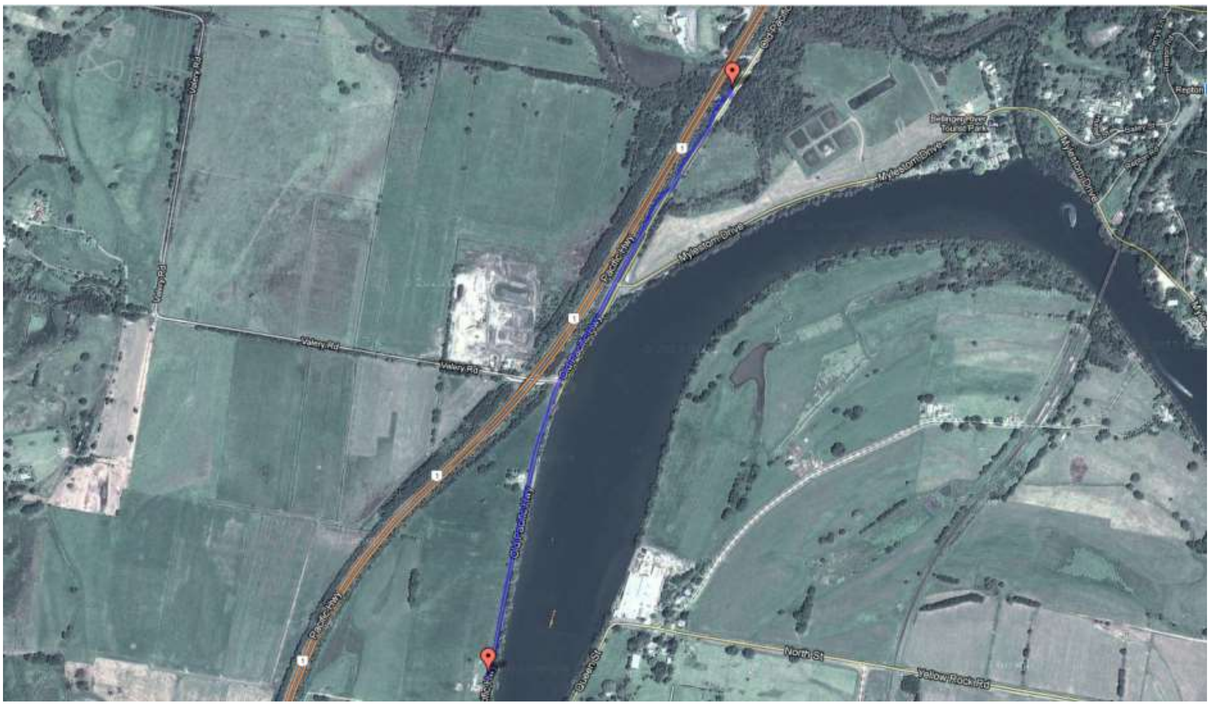
This picture also shows a similar line to the others by this device having a perfect line.

Results from Device 3

Repetition 1

From the picture the GPS appeared to measure rather accurately, but the results contradict this measuring further than the actual distance.

Repetition 2



This picture also indicates a perfect line but as with repetition 1, the distance measured was long.

Repetition 3

This repetition also follows the trend of this device measuring long.

Device 4

Repetition 1

From this picture it appears that the line that has been drawn is perfectly on course, however the distance measured was also longer than the control.

Repetition 2

The GPS appears to have taken the correct reading but the results offer different information reading a larger distance then was actually travelled.

Repetition 3

This repetition follows the same consistent trend as the rest of the other devices appearing to measure the correct distance but actually measuring over. Although you cannot see it in this image the device had the starting point in the river.

Course 1 conclusion

Course one is a straight course that negates some major variable such as corners and hills. Despite this the GPS measuring devices consistently measured longer than the actual distance measured by the control, proving the hypothesis wrong for a straight course. Device one was the most accurate device only misreading 0.01 of a kilometre out. Device four was the next most accurate with minor miscalculations. Device two and three were much further out than the other two devices measuring out by 0.1 of a kilometre.

Course 2

Course two is an undulating course with a mixture of straights and corners. The course is 5.7 kilometres long and will be ridden three times. Below is a table of results and pictures of where the GPS located itself during the test.

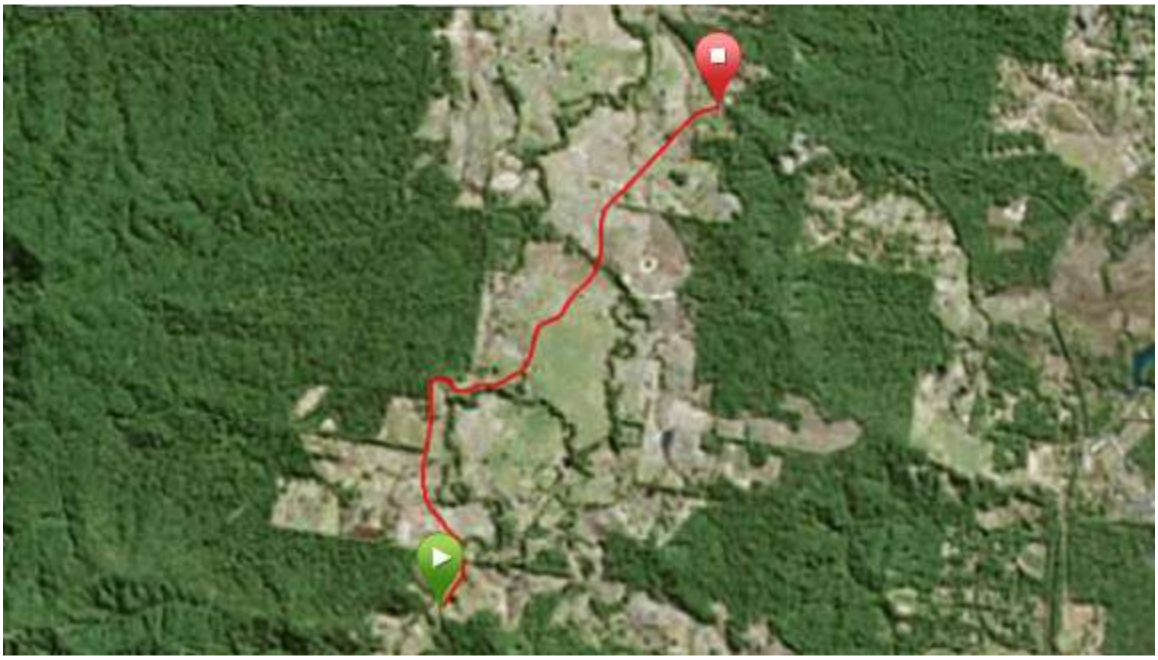
Device	Repetition 1	Repetition 2	Repetition 3
Device 1	5.70km	5.71km	5.70km
Device 2	5.80km	5.90km	5.90km
Device 3	5.74km	5.81km	5.52km
Device 4	5.80km	5.84km	5.83km
Control	5.70km	5.70km	5.70km

Results from Device 1

Repetition 1

This map clearly indicates that this device was accurate at measuring the distance which we can see not only in this picture but also the results.

Repetition 2



This picture is very similar to the one in the first repetition and also nearly as accurate although it measured 0.01 of a kilometre longer than the control.

Repetition 3

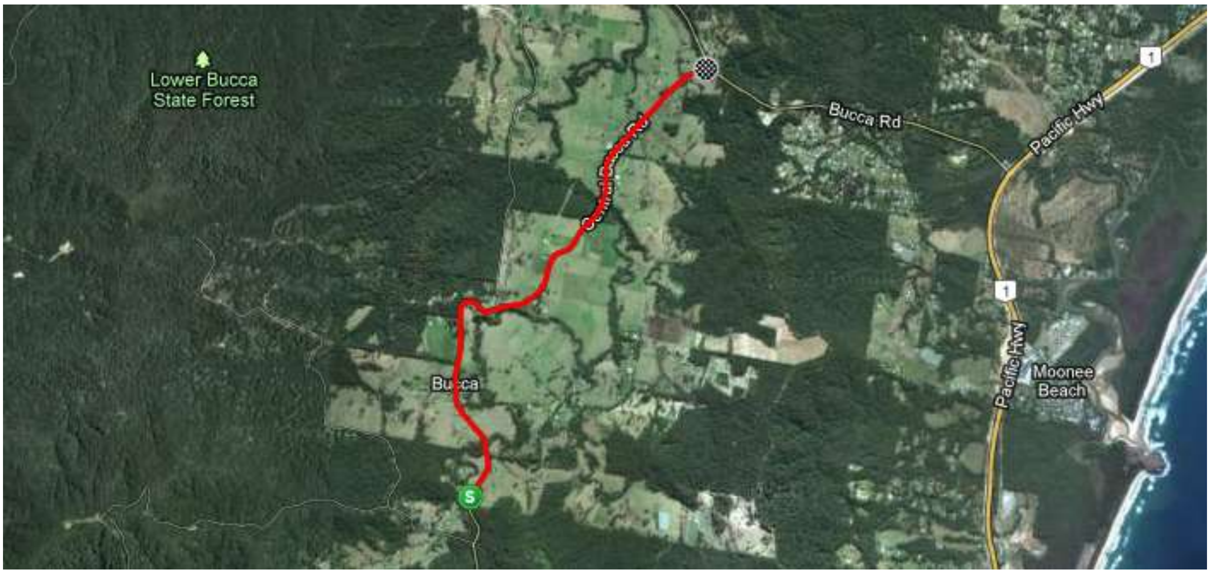
This picture follows the trend made by the other repetitions from this course by device one. This map and distance is accurate.

Results from Device 2

Repetition 1

Although this map looks accurate the distance for this repetition was long by 0.1 kilometre from the distance that was measured by the control.

Repetition 2



This repetition is much like the first with an accurate map and inaccurate result. This was over by 0.2 of a kilometre.

Repetition 3

This map and result is nearly identical to the first repetition. Both the map and the result were 0.1 kilometres over the control distance.

Results from Device 3

Repetition 1

This picture shows the accurate map but an inaccurate distance measuring over by 0.04 of a kilometre.

Repetition 2

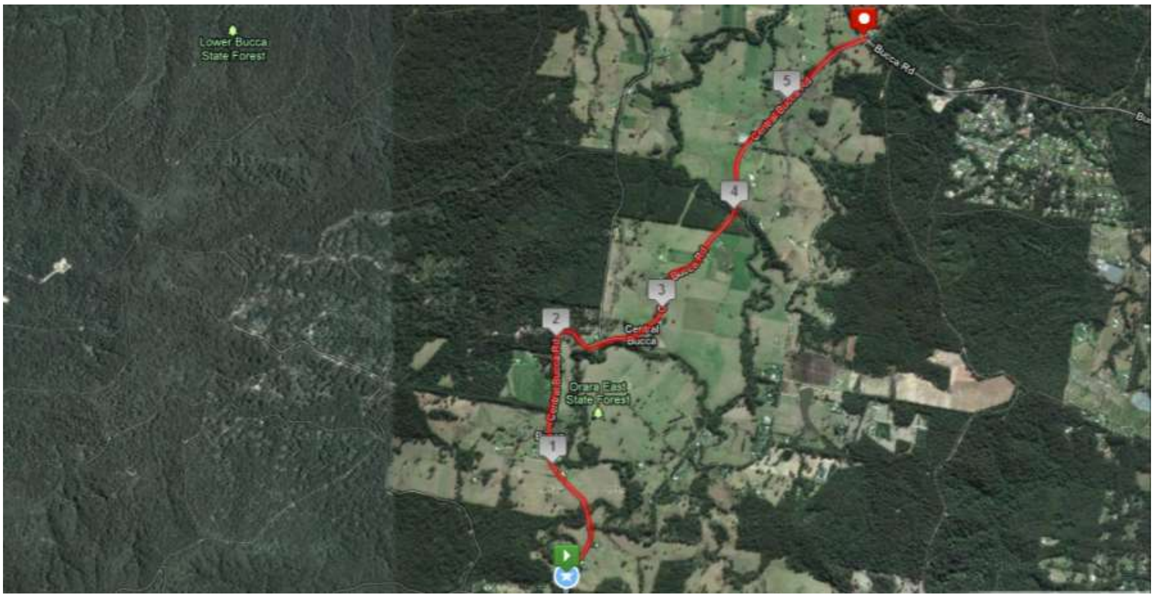
This result is also accurate on the map, but inaccurate in distance measuring over by .11 of a kilometre.

Repetition 3

This follows the trend set by device three, it has an accurate mapped representation but distance is inaccurate measuring short by 0.18 of a kilometre.

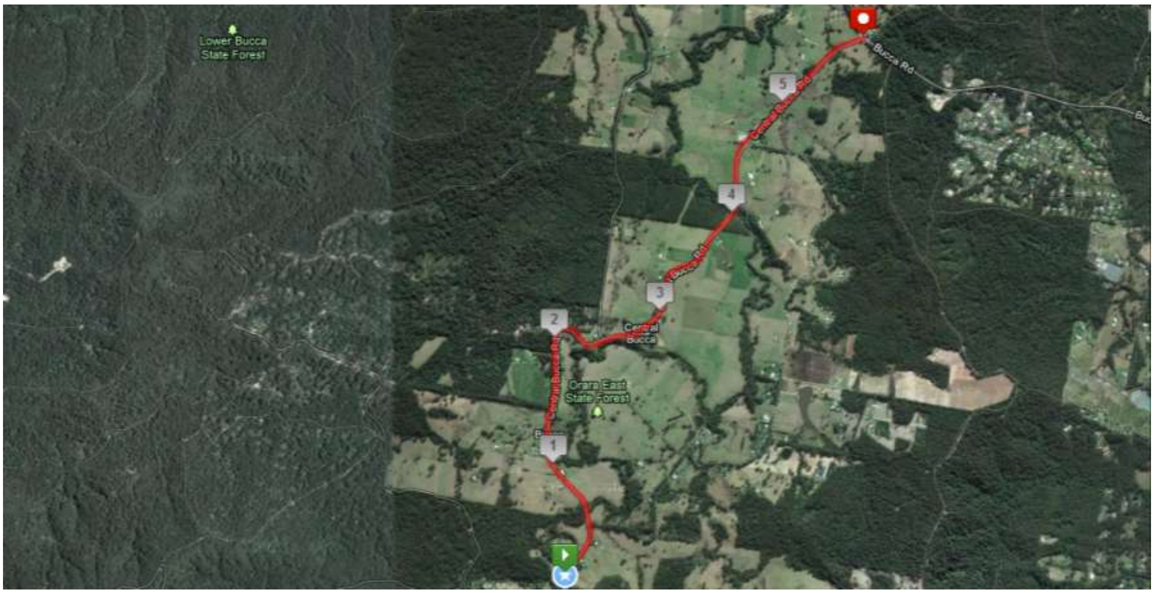
Results from Device 4

Repetition 1



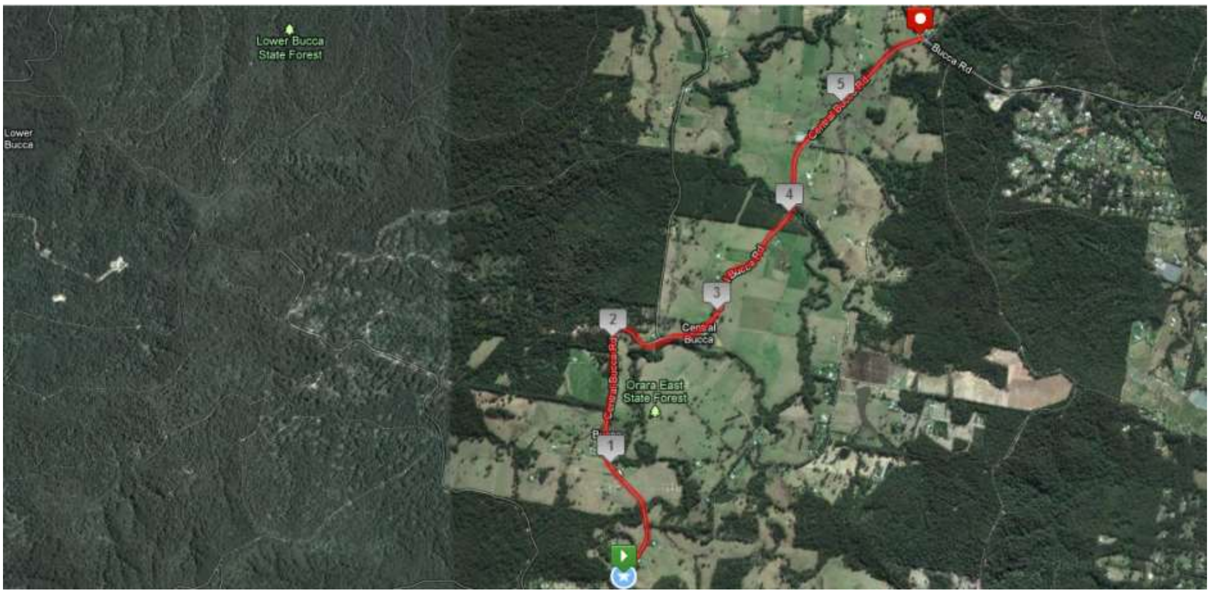
This map has the line moving back and forwards across the road leaving the map inaccurate. The distance was also inaccurate being 0.1 of a kilometre over the distance the controls measured.

Repetition 2



This picture shows the same image as the first repetition, a few movements that were not actually present and due to this an inaccurate result. The measurement was 0.14 kilometres long compared to the control.

Repetition 3



This image shows a similar trend to the rest of the maps above, an inaccurate GPS mapping and therefore an inaccurate result measuring 0.13 kilometres long.

Course 2 conclusion

This course was undulating and had a mixture of corners and straight sections. Device one was the most accurate, measuring slightly over by 0.01 of a kilometre. The rest of the devices were all inaccurate measuring up to 0.2 of a kilometre longer than the distance recorded by the control, although most still plotted an accurate map. Only one device, device 3 measured short for one repetition, the other two repetitions were both long. Device 4 registered as taking a longer route around corners and went back and forth across the road in several places.

Course 3

Course three is a circular course which is 333 meters in length. This course is ridden 6 times to create one repetition making this route 2 kilometres long. Below is a table of the results as well as the pictures showing the GPS track.

Device	Repetition 1	Repetition 2	Repetition 3
Device 1	2.00km	2.05km	2.02km
Device 2	2.00km	2.00km	2.00km
Device 3	2.05 km	2.10 km	2.14 km
Device 4	2.64km	2.72km	2.68km
Control	2.00km	2.00km	2.00km

Results from Device 1

Repetition 1

From the picture above and the distance measured this GPS measurement is accurate.

Repetition 2

The GPS measured rather wide on this corner and has plotted the device as traveling through the grass. We can see this significant change of course in the distance measured by the device. The distance measured was 0.05 kilometres long.

Repetition 3

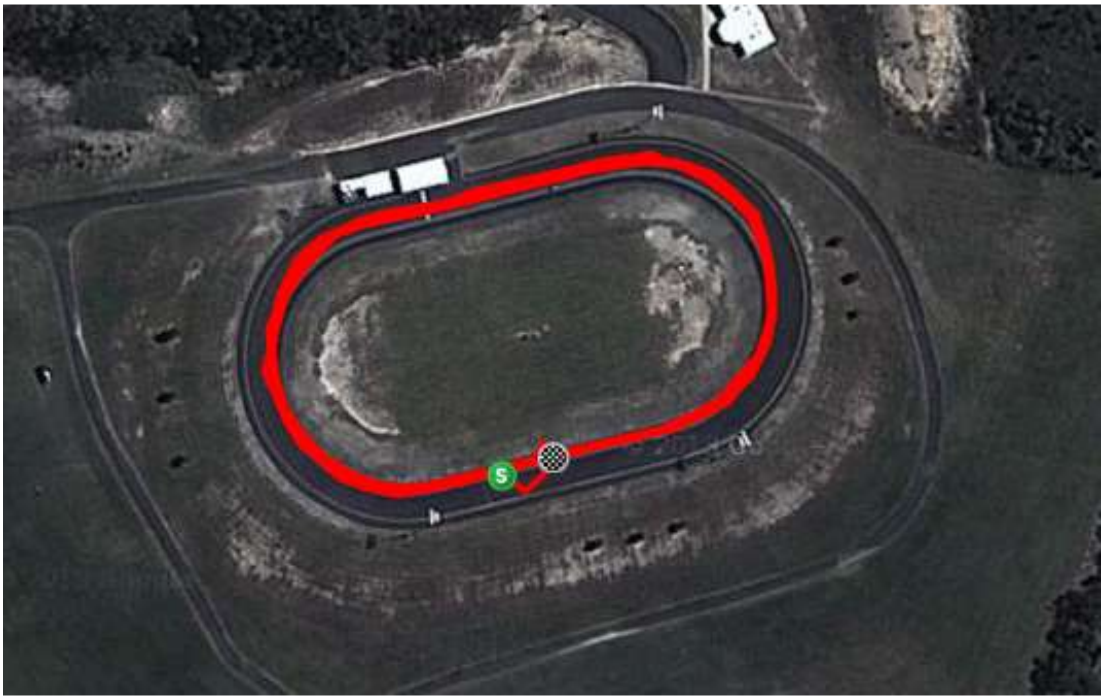
This picture indicates that the device plotted wide in the right corner. We also see this in the recorded distance being over by 0.02 kilometres.

Results from Device 2

Repetition 1

Form this picture we can see that the device is very accurate. We do see though that there are two stray point away from actual line, although this does not appear to effect the results.

Repetition 2



This picture shows an almost perfect line with one deviant at the start-finish mark. We can also see the accuracy of this repetition in the results which are the same as the control.

Repetition 3

This picture is much the same as the others from this device, following the actual line and distance. There is one small deviation at the start mark again.

Results from Device 3

Repetition 1

This picture shows that this device's smoothing process did not properly function and took a direct straight line through one corner making it appear as though it would have taken less distance to complete the course but it is recorded as being longer by 0.05 kilometre.

Repetition 2

The image above includes skipping sections of the left corner in the same way as the repetition above, but still over measured the distance by 0.1 kilometre.

Repetition 3

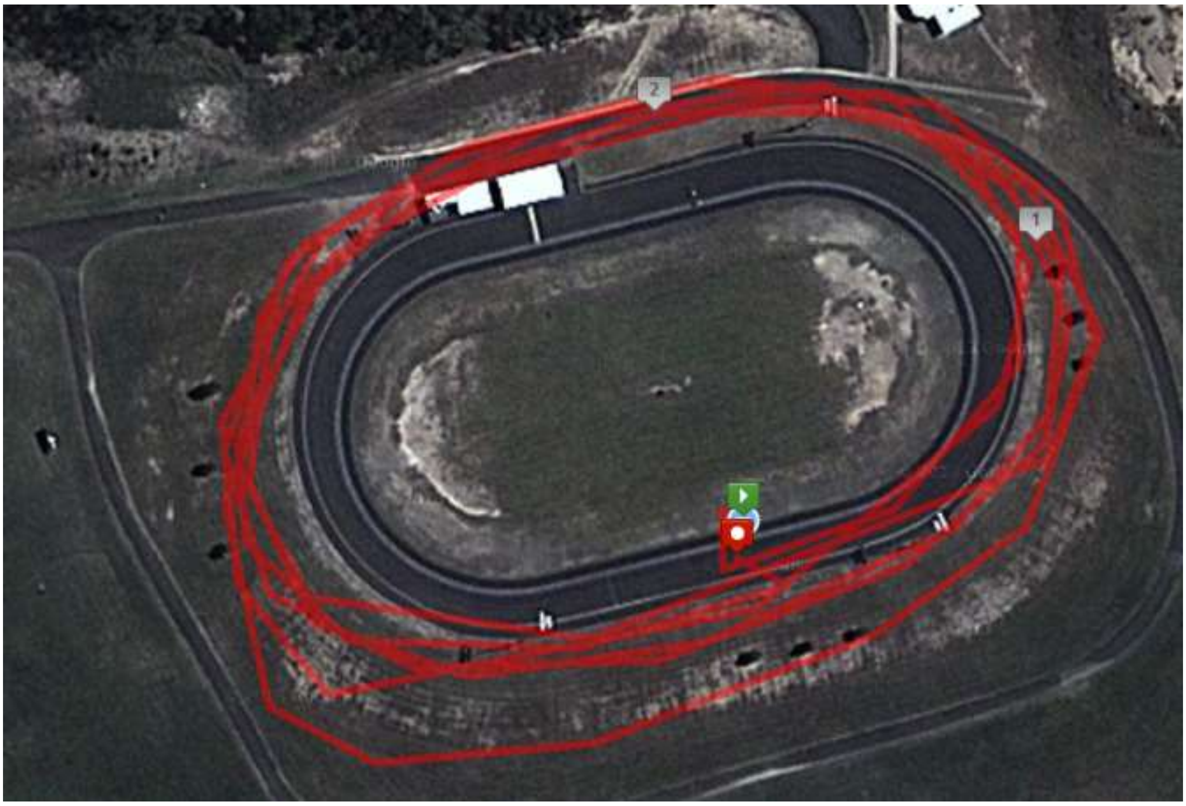
From the picture it appears that the line has a few minor deviations from the correct line making the distance longer than the device actually moved. It measured 0.14 kilometres long.

Results from Device 4

Repetition 1

This device has measured drastically off course, this may have been caused by smoothing process. The result measured 0.64 kilometres long.

Repetition 2



This picture has a much wider turning circle then the actual line which was taken making the distance much larger than it actually is. This measured 0.72 kilometres long.

Repetition 3

This repetition follows the trend for this device measuring a larger turning circle than the course. It measured 0.68 kilometres long.

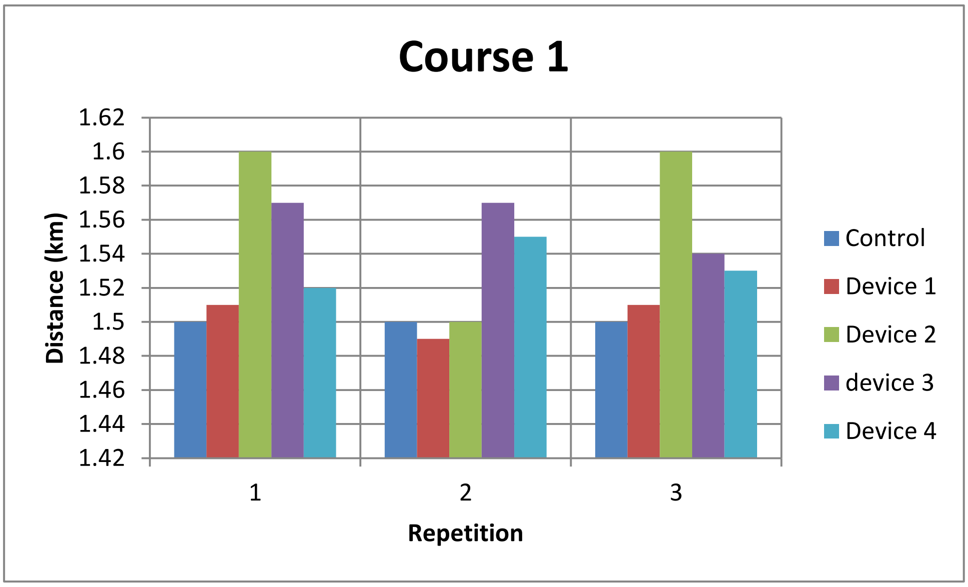
Course 3 conclusion

This was a constant corner and therefore created some interesting results. Device one had a perfect first repetition but the second and third had some inaccuracy taking longer to get around the course than the distance that was actually travelled. In contrast the second device measured accurate distance consistently. Device three skipped segments of the corner but still over measured. But device four was the least accurate consistently measuring a larger turning circle which was likely caused by the smoothing process of the software.

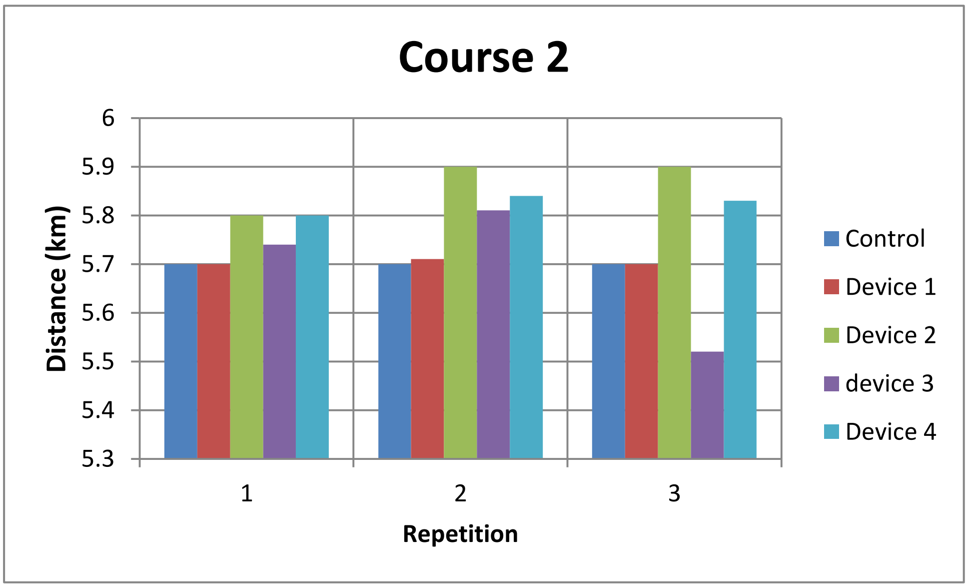
Analysis

The graphs below show the data for all courses:

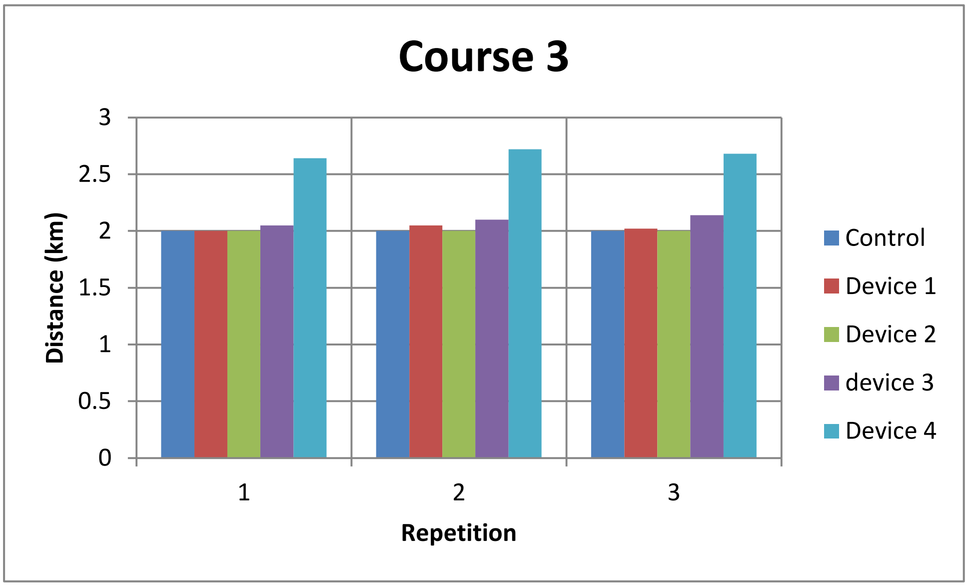
Course one has a large spread of data most of it being larger than the control. If the hypothesis was correct all of the data should be equal to or below the control. Therefore the hypothesis is false for course one. The difference between devices is also large although device one was consistently more accurate than any of the other devices.



Course two shows similar results to course one disproving the hypothesis yet again. Device one is the most consistent concurring with course one. There rest of the devices recording a much higher difference from the control



and device three had one repetition lower then control, this result was an outlier.



Course three is the most consistent on each repetition than the other two courses although it still proved the hypothesis wrong. What is different from this result compared to other courses is that device two is the most accurate. Also there is a smaller spread of data.

Discussion

The results from this experiment do not give support to the hypothesis that a device that uses a GPS to measure a distance travelled will always measure shorter than the actually distance due to the process in which data points are interpreted. These inconsistencies with the results may be due to a problem with either the GPS or the software's interpretation of the data points produced by the device.

The course on the velodrome with the most amount of corners surprisingly resulted in the most consistent results in 3 out of the 4 devices. However the one device which was an outlier, measured the most inaccurate results for this course of all the courses. The straight course was also in contrast to what was expected as it resulted in the most amount of variation between the devices.

The hypothesis was based on the idea that the software would 'cut corners' and measure short. However it appears the smoothing software in fact made deviations that were longer not shorter. This was observed on the results of the tracking on the maps. It was not clear however if the measuring long was the result of the GPS device or the software.

This experiment used both a different device and a different software program for each course. To improve the design of this experiment, each device should have the course repetitions conducted using each piece of software used in the experiment. This would determine if the inaccuracy was due to the GPS device or the software 'smoothing' program.

The sample size of devices and software for this experiment was only small. A larger selection of devices and software would also improve the results and reliability.

Conclusion

In conclusion the experiment did not provide supporting evidence to the hypothesis that a device that uses a GPS to measure a distance travelled will always measure shorter than the actual distance due to the process in which data points are interpreted. Results showed that different devices and software gave less accurate data. Therefore a device that uses a GPS to measure a distance travelled will not always measure shorter than the actual distance due to the process in which data points are interpreted. In relation to the aim, the GPS devices did not accurately measure distance travelled when compared to the control device, the speedometer.

- [1]http://www.gps-basics.com/faq/q0121.shtml
- [2]http://www.spaceweather.gc.ca/se-gps-eng.php
- [3]http://cheryl.nbmg.unr.edu/publications/gpsworld.may98.pdf
- [4]http://gpsinformation.net/main/gpslock.htm
- [5]http://connect.garmin.com/
- [6]http://app.strava.com/
- [7]http://www.google.com/mobile/mytracks/
- [8] http://www.mapmyride.com/
- [9] http://stackoverflow.com/questions/1134579/smooth-gps-data
- [10] http://www.gmat.unsw.edu.au/snap/gps/gps_survey/chap6/6411.htm
- [11] http://www.gmat.unsw.edu.au/snap/gps/gps_survey/chap7/742.htm
- [12]http://support.echoview.com/WebHelp/Using_Echoview/Cruise_track/Processing_and_smoothing_cruise_tracks.htm
- [13]http://commuteatlanta.ce.gatech.edu/Resources/kalman%20filter%20revised%20trb%20v5%20jjrg%20111805%2006-2907.pdf
- [14] http://www8.garmin.com/aboutGPS/
- [15] http://www.insidegnss.com/node/2512