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COURSE MEASUREMENT

This page is a summary of results of some of the research we have recently conducted towards applying conventional surveying techniques to course measurement. We have experimented with three measurement techniques:

- calibrated bicycle;
- DGPS; and
- aerial photogrammetry (results will be published when available).

DGPS Survey for Course Measurement

CALIBRATED BICYCLE METHOD

The calibrated bicycle method is the only certified course measurement technique. It involves installing a mechanical JO counter onto the fork of a bicycle. The bicycle is cycled over the race route and the JO counter records the number of revolutions of the bicycle wheel. The number of revolutions is scaled to a meaningful distance through calibration. This involves cycling over an accurately known distance several times before and after the measurement of the race route.

As part of our on-going research into investigating other course measurement techniques (e.g. DGPS), we needed to determine the measurement precision of the JO counter. The following three experiments show the results from multiple observations over different length routes. In Experiment I, the route is a 1km straight road. Experiment II is a 2.9km closed circuit which is almost independent of SPR. The final experiment involves a 10km race route.

To facilitate the trials, we purchased two JO counters and borrowed a third from a local certified course measurer, Bob Braid (Runner's World). Please note that the people involved in these experiments are not certified course measurers and do not possess extensive course measuring experience. However, we are experienced surveyors.

Experiment I - *JO Counter Testing on a 1km Baseline*

This experiment was situated at the 1km baseline on Labouchere Road, Perth. The baseline was setup by Bob Braid. The baseline is split into a 1km west and 1 km east baseline. The purpose of this experiment was to determine the precision of the JO counter for a straight flat section of road.

Figure 1. *Looking south down the 1km baseline (Click for larger image)*

The baseline was originally set out by a surveyor. However, prior to commencing these JO counter measurements, the west and eastern baselines were measured using a pre-calibrated total station (i.e. EDM). The total station is rated at +/-4mm over this distance. The distance measurement was also corrected for systematic effects of temperature and pressure. Each baseline was determined to be 1000m.

The baseline was also levelled using a digital level. The southern end of each baseline was determined to be 1.5m higher than the northern end. The slope is a gradual incline from north to south. The baseline can be considered flat for these experiments.

Two cyclists measured the baseline multiple times (on different days). Temperature was also observed. The computed counts for each cyclist is shown in the table below. All cyclists are labelled with their first name initial so that comparisons can be made between the three experiments.

The precisions of the cyclist S and T are approximately +/-0.099m and +/-0.133m, respectively. It is unknown why the counts on the western baseline were consistently higher than the eastern. Contributing factors include the gradual slope (though very small) and wind (which typically comes from the same direction, from the SW in the afternoon).

	Cyclist S		**Cyclist T**	
Lap	West	East	West	East
1	12065	12059	11314	11309
2	12068	12061	11312	11312
3	12068	12061	11313	11310

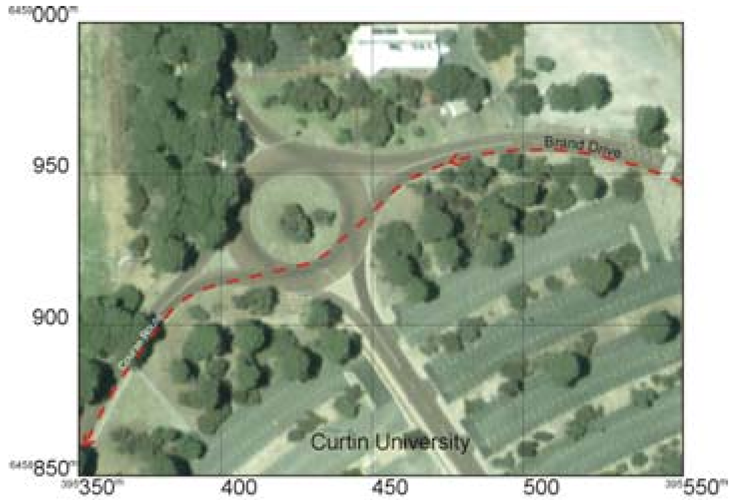
4	12069	12060	11312	11310
5	12068	12060	11314	11313
6	12068	12060	11310	11311
7	12069	12060	11311	11308
8	12068	12059		
9	12067	12063		
Median (counts)	12068	12060	11312	11310
Mean (counts)	12067.8	12060.3	11312.3	11310.4
Standard Deviation (counts)	+/-1.2	+/-1.2	+/-1.5	+/-1.7

Experiment II - *2.9km Controlled Route (no SPR)*

This experiment was to assess the precision of the JO counter on a route that was undulating and involved curves. The route was not a race course but a 2.9km circuit within the Curtin University campus (on-line map here). The advantage of this circuit is that no vehicles are allowed to park anywhere along the route. Furthermore, the traffic was always very light and posed no hindrance to the cyclists.

Figure 2. *Aerial photograph of Curtin campus (Click for larger image).*

The 2.9km route is a closed circuit (start/finish location were coincident). The circuit also has a pre-defined SPR that can be directly followed by the cyclist, the cyclists simply had to maintain a distance of 400mm from the kerb for most of the entire route. There were only 3 instances where the cyclist had to leave the kerb (at roundabouts). Therefore, this experiment is able to test the JO counter almost independent of route definition. Figure 2 (below) shows a section of the route where the cyclists were forced to leave the kerbside to transit through a roundabout. These were the only instances where the course measurers were forced to make decisions regarding the route of the course.



Note: Coordinates are in Map Grid of Australia (MGA).

Figure 3. *Section of the 2.9km course showing route deviating from the kerb through a roundabout (Click for larger image).*

The following table shows the results for 3 cyclists. Cyclist M and cyclist S obtained their measurement on the same day but cyclist T obtained his measurements on a separate day. All bikes were pre- and post-calibrated on the Labouchere Road baseline following standard guidelines (i.e. 4 laps per baseline) to establish a constant.

Note: the short course prevention factor (SCPF) was **not** applied to any measurements in this experiment.

	Cyclist S		**Cyclist M**		**Cyclist T**	
Lap	Count	Distance (m)	Count	Distance (m)	Count	Distance (m)
1	34915	2901.18	31944	2898.42	32821	2901.03
2	34906	2900.43	31959	2899.78	32813	2900.32
3	34904	2900.27	31963	2900.19	32813	2900.32
4	34902	2900.10	31974	2901.14	32804	2899.53

5	34892	2899.27	31971	2900.92	32802	2899.35
6	34891	2899.19	31964	2900.28	32802	2899.35
7	34921	2901.68	31964	2900.24	32815	2900.50
8	34903	2900.18	31967	2900.55	32809	2899.97
9	34901	2899.98	31977	2901.46	32809	2899.97
10	34896	2899.60	31961	2900.01	32808	2899.88
11	34892	2899.27	31963	2900.19	32811	2900.15
12	34898	2899.77	31974	2901.19	32813	2900.32
Median	34901	**2900.04**	31964	**2900.26**	32810	**2900.06**
Mean	34901.7	**2900.08**	31964.9	**2900.36**	32810.0	**2900.06**
Std. Dev.	+/-9.2	+/-0.76	+/-8.9	+/-0.81	+/-5.6	+/-0.49

The mean of cyclist S and cyclist T differed by only 20mm. The mean distance of cyclist M was only 300mm different than the other two cyclists, less if you consider the median values (a median statistic devalues outliers in the observation set).

Experiment III - *10km Race Route*

The objective of experiment III was to assess the precision of the calibrated bicycle method over a 10km road race course. Unlike the previous two experiments, SPR was a factor. Each cyclist was asked to cycle one lap of the 10km route observing their definition of SPR. Once they had established this path, their following five laps had to repeat this path as close as possible (i.e. to their interpretation of the SPR).

The 10km race route is composed of mostly pedestrian pathways and a small percentage of vehicular roads. Therefore, obstacles included pedestrians and cars. This experiment was also combined with an investigation into GPS for course measurement with these results presented further below on this page.

Below is a table of results for 4 cyclists each with a JO counter after acquiring 6 laps of the (approximate) 10km course. The measurements are the mean values of each rider's 6 laps of the course. The standard deviation for each cyclist's 6 laps are commensurate although the mean values are, in some cases, markedly different.

Method	Median Distance (m)	Mean Distance (m)	Standard Deviation (m)	Laps
JO Counter S:	10,041.8m	10,042.4m	+/-3.3m	6
JO Counter				

N:	10,044.4m	10,045.6m	+/-2.2m	6
JO Counter M:	10,066.4m	10,068.0m	+/-4.5m	6
JO Counter T:	10,165.2m	10,165.8m	+/-2.7m	6

Summary of JO Counter Experiments

These results show that the reputation of the calibrated bicycle method is justified in terms of precision. As professional surveyors, we cannot think of any faster conventional survey technique for the measurement of complex race courses.

Furthermore, the numbers computed for the repeatability of the JO counter also justify the magnitude of the SCPF.

As course measurers are aware, the major uncertainty with the calibrated bicycle method is not with the precision of the JO instrument itself, rather the subjective definition of the shortest possible route by the measurer. Results from experiments II and III clearly illustrate this point. In experiment II very little margin of error was available to the measurers in terms of interpretation of the SPR, resulting in an excellent agreement between the 3 cyclists, whereas results from experiment III were much more variable. In this case, cyclists S and N tended to cycle the course together, hence following a similar route. Therefore whilst their results are in agreement, in statistical terms, they are not independent.

Cyclist M, whilst on the course at the same time as S and N, being older and slower could not keep up with his younger colleagues. Therefore, he followed his own interpretation of SPR.

Cyclist T measured the course at a different time and date, only using official race maps supplied by Bob Braid and anecdotal information from the previous measurers. Interestingly, his measurements were of similar precision to cyclists S and N, but his final measured distance varied substantially from the other three.

This course has also been measured by Bob Braid, the local 'professional' course measurer. We haven't included his results because of uncertainty of the start and stop positions of his measurements. However, based on his plans, it is clear that Bob adopted a more aggressive approach to SPR than the four of us, for example measuring directly across the middle of a roundabout, whereas all four measurers here, chose to keep on the road and cycle around the roundabout. This is where a permanent record of the path actually taken by any measurer would be extremely useful and in our opinion, it is the lack of this permanent record of the path travelled which is the main weakness of the calibrated bicycle method. Given the differences caused by SPR interpretation (which become apparent even when a number of the most experienced course measurers observe the same circuit, e.g. in the 1996 Atlanta Olympic marathon course measurement where 25 measurers cycled the course) the calibrated bicycle method is somewhat difficult to quality control.

Below we test two survey methods which it has been suggested could solve the route definition issue.

DGPS

DGPS, or differential GPS, involves processing GPS observations to remove some systematic errors thus improving the GPS measurement accuracy. The main differences of DGPS over (hand-held) GPS are:

- differential corrections are received from a base station;
- survey software was used to (post-)process the observations from both receivers; and
- the single-point accuracy of DGPS is at the metre level whilst GPS positioning is about 10 metres in the horizontal.

During experiment III, DGPS was also used to investigate if it could yield the same distance as that determined using the JO counter. The DGPS receiver used in this experiment is a relatively good handheld GPS unit firmly affixed to the handlebars of one of the bikes (the bike also had a JO counter attached). A basestation was set over a known point on our university campus about 5 km away. It is possible to see the setup on the image at top right of the web page.

One of the aims of our experiment was to investigate if DGPS is able to provide better results for course measurement than standard point-positioning with a handheld GPS receiver.

DGPS suffers the same problems as any GPS surveying methodology, such as loss of signal due to line-of-sight occlusions. The following figures are included to show some of our experiences. Our experiment was conducted using a 10km course in Perth, Western Australia. The red lines are the routes digitised using aerial photogrammetry and the green dots are individual DGPS observations.

Figure 4 (below) is an example of loss-of-lock caused by cycling under a traffic bridge (i.e. no observations recorded except for some outliers that appear in the water). There is also scatter caused by cycling under some trees.

Figure 4. *Loss of observations due to loss of sky visibility (Click for larger image)*.

Figure 5 (below) is an example showing how DGPS obtained the correct route under the canopy of trees (top right of the figure) but aerial photogrammetry failed to get the correct route. The DGPS and photogrammetry show good agreement for most of this area, due largely to the relative clear sky visibility. There is some scatter near the two-storey buildings at the top-left of the figure.

Figure 5. *Incorrect route of aerial photogrammetric mapping versus DGPS (Click for larger image)*.

Figure 6 (below) shows the start (centre-right of figure) and end (centre) of the 10km course. The red line correctly shows the start of the course (it was marked with painted lines on the bitumen) but the DGPS was unable to precisely define the starting location and was incorrect by several metres.

The red line (aerial photogrammetry) shows how easy it is to maintain the shortest possible route around corners but the green dots show that DGPS fails to maintain the correct route. Note: the route makes one lap of the river before coming back onto itself to finish near the start, hence the two red lines along the same path.

Figure 6. *Start and end of the course (Click for larger image)*.

Overall, the DGPS failed to yield an accurate solution. In an attempt to improve the quality of the DGPS, we mathematically smoothed the route consisting of several thousand 3D GPS points, hence eliminating spurious points. However, the route defined by the DGPS was still too inaccurate compared to the JO counter (see the table of results for experiment three)

Method	**Mean Distance (m)**	**Standard Deviation (m)**	**Laps**
DGPS:	10,587.6m	+/-307.7m	6

AERIAL PHOTOGRAMMETRY

Aerial photogrammetry is a well established surveying technique that permits the extraction of 3D coordinates of features visible in overlapping aerial photographs. Plotting of the route occurs in stereo using 2 photographs taken from different locations but of mostly the same area and, in the case presented here, in a digital environment using surveying software. Advantages of digital photogrammetry include:

- accurate and precise 3D measurements;
- remote measurement (i.e. no contact with busy roads);
- surface independent (e.g. sand, water);
- permanent visual record of the actual route measured; and
- it provides an instant "photographic" map of the course (including elevations).

Results under construction.

We intend to publish additional results in the near future. We welcome any comments regarding our research, which can be forwarded to my email address below.

Stuart Gordon
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Links: Road Race Course Measurement Bulletin Board

Look ever forward
Curtin University of Technology
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