Rapid Mapping
with Post-Processed Garmin Data

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BIOGRAPHIES

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ABSTRACT

GRINGO (GPS RINEX Generator) is a program which has been developed at the Institute of Engineering Surveying and Space Geodesy (IESSG) at the University of Nottingham, to record the pseudorange and full carrier phase data from 12-channel Garmin handheld GPS receivers, in standard RINEX (Receiver INdependent EXchange) format. It offers owners of these receivers the possibility of post-processing to an accuracy of approximately 5 m (with pseudoranges) or even a few centimetres (with carrier phase), without having to invest in separate DGPS receiving equipment or expensive survey-grade receivers. They retain the benefits of an inexpensive receiver with a user-friendly interface and powerful navigation features, but gain the possibility of improved accuracy if needed. This accuracy could be of use to all manner of navigation, mapping and GIS applications, where the accuracy achievable with stand-alone GPS is insufficient.

A number of experiments have been carried out to assess the accuracy of positioning with Garmin raw measurement data. For example, a zero baseline test, with two Garmin receivers attached to a single static antenna, has shown that under ideal conditions, sub-centimetre accuracy can be achieved with carrier phase measurements. Recently a new project considered the use of Gringo for the rapid production of a new orienteering map.

This paper will present the background to the Gringo software and its operations, and will describe the recent survey and results.

INTRODUCTION

Handheld GPS receivers are becoming increasingly popular among outdoor enthusiasts and other leisure users. Public awareness of GPS has risen and prices have dropped to the point where these devices are now common in highstreet consumer electronics shops. With a growing market place and increasing turnover, manufacturers have been able to increase the performance and capabilities of handheld GPS devices, and many now sport an impressive array of features, such as the ability to apply received differential corrections in real-time, and built-in and/or uploadable mapping.

In May 2000, the US Department of Defense removed their artificial degradation of the GPS signals, known as Selective Availability (SA), and overnight the horizontal accuracy of GPS improved from a specified 100 m (2drms) to somewhere around 10 m – we all had a free upgrade. Nevertheless, there are many applications for which even this accuracy is not sufficient, and the technique of differential positioning, or DGPS, which prospered under SA, can still provide a useful improvement to the stand-alone accuracy. DGPS compensates for common error sources such as atmospheric delays, and can give accuracies of better than 5 m. The use of carrier phase measurements can improve the performance still further, either by smoothing the basic range measurements, or through the use of interferometric processing techniques to yield relative coordinates with an accuracy of a decimetre or better.

Until recently, users wishing to make use of these techniques have had a couple of options open to them. Firstly, receivers which accept DGPS corrections as input can use these corrections to compensate for common error sources in real-time, and yield accuracies of the order of 5 m. However, this requires the user to carry additional receiving equipment in order to pick up the DGPS broadcasts, if they are available, and feed them into the GPS receiver. Alternatively, board-level and survey-grade GPS receivers provide access to the raw GPS observables, namely the pseudoranges and the carrier phase measurements. Depending on the type of receiver, these raw measurements can either be recorded in internal memory, or logged to an attached computer, and then post-processed in conjunction with data from reference receivers. This option, by virtue of the access to the carrier phase observations, provides the highest level of accuracy, typically a few cm, but usually at a cost. Besides being significantly more expensive and bulky than handheld receivers, survey-grade receivers do not usually come equipped with user-friendly navigation firmware or features such as built-in base mapping, while board-level receivers are designed and sold to be used by Original Equipment Manufaturers (OEMs) or as the basis of a custom-built system, in which the user adds keypad, screen and logging interfaces according to particular requirements.

WHAT IS GRINGO?

GRINGO (GPS RINEX Generator) is a program which has been developed at the Institute of Engineering Surveying and Space Geodesy (IESSG) at the University of Nottingham, to record the pseudorange and carrier phase data from a particular range of handheld GPS receivers, in standard RINEX (Receiver INdependent EXchange) format. It offers owners of Garmin 12-channel receivers the possibility of post-processing to an accuracy of approximately 5 m (with pseudoranges) or 10 cm (with carrier phase), without having to invest in separate DGPS receiving equipment or expensive survey-grade receivers. They retain the benefits of an inexpensive receiver with a user-friendly interface and powerful navigation features, but gain the possibility of improved accuracy if needed.

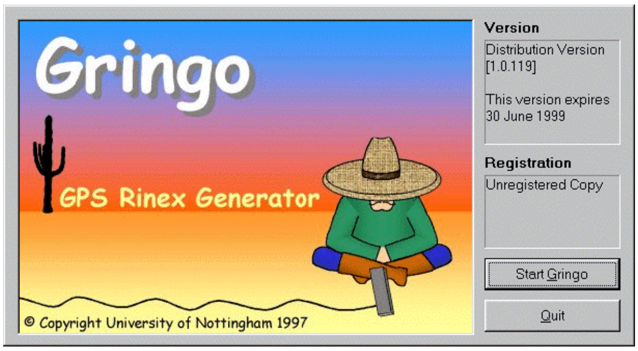

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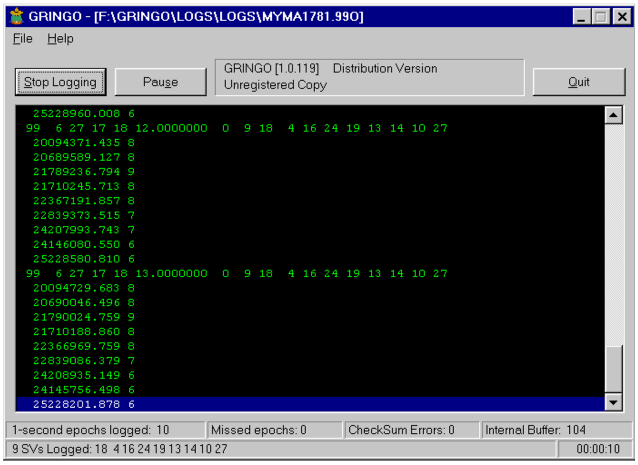
Figure 1 – GRINGO Splash Screen

HOW IS IT DONE

In addition to industry-standard protocols for DGPS input (RTCM) and coordinate exchange (NMEA), Garmin receivers use a proprietary data format to allow internal waypoints, tracks and other information to be exchanged with a computer or another Garmin receiver. Even before parts of this so-called Garmin Communications Protocol were officially published by Garmin, most of the important parts had been decoded and published on the internet by a small number of interested users of the Garmin receivers. A great deal of software, from free utilities to shareware and fully commercial programs, has been written to make use of the Garmin Communications Protocol. However, there is still quite a lot of information that the Garmin receivers output using this protocol, which is not documented by Garmin. According to Garmin, these 'undocumented protocols' are intended as engineering and manufacturing 'testing aids'.

GRINGO's authors have deciphered parts of some of the undocumented protocols, which appear to contain the raw pseudorange and carrier phase measurements necessary for post-processing. GRINGO is a Windows program which decodes the relevant protocols and logs the raw data to a file using the widely accepted RINEX format. Users must connect their Garmin receiver to a serial port on their laptop computer, and run GRINGO in real-time to capture the pseudorange data as the measurements are generated and output (Figure 2). For users who do not have access to a suitable laptop for field use, a companion program has also been developed for the Psion Series 3mx PDA and the Psion Workabout mx. This companion program captures the necessary data from the Garmin receivers, in a format which GRINGO can later decode to produce a RINEX file.



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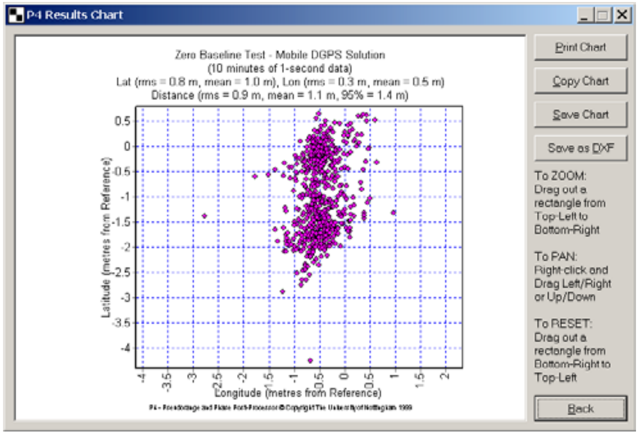
  25228960.008 6
 99  6 27 17 18 12.0000000  0  9 18  4 16 24 19 13 14 10 27
  20094371.435 8
  20689589.127 8
  21789236.794 9
  21710245.713 8
  22367191.857 8
  22839373.515 7
  24207993.743 7
  24146080.550 6
  25228580.810 6
 99  6 27 17 18 13.0000000  0  9 18  4 16 24 19 13 14 10 27
  20094729.683 8
  20690046.496 8
  21790024.759 9
  21710188.860 8
  22366969.759 8
  22839086.379 7
  24208935.149 6
  24145756.498 6
  25228201.878 6
```

1-second epochs logged: 10 | Missed epochs: 0 | CheckSum Errors: 0 | Internal Buffer: 104
9 SVs Logged: 18 4 16 24 19 13 14 10 27 | 00:00:10

Figure 2 - Data Logging screen from GRINGO

POST-PROCESSING

With the appropriate processing software, a RINEX pseudorange data file can be combined with a data file from another ('reference') receiver, to measure the vector between the receivers. If the coordinates of the reference receiver are known to a high accuracy, the coordinates of the Garmin receiver can be determined from pseudorange measurements to an accuracy equivalent to DGPS. With carrier phase measurements, the vector between the reference station and the Garmin receiver can be measured to an accuracy of 10 cm or better. Of course, such accuracies cannot be guaranteed, as many factors can influence the performance of a GPS receiver, and hence the precision of the decoded data. GRINGO comes with a Pseudorange and Phase Post-Processor (P4), which is optimised for the task of handling RINEX files of Garmin pseudorange and carrier phase data. P4 provides all the options necessary to compute stand-alone, DGPS or carrier phase positions. It provides a statistical and graphical analysis of the resulting positions (Figure 3), as well as providing details of the observations used in the computations (Figure 7, Figure 9).



To ZOOM:
Drag out a rectangle from Top-Left to Bottom-Right

To PAN:
Right-click and Drag Left/Right or Up/Down

To RESET:
Drag out a rectangle from Bottom-Right to Top-Left

Figure 3 - Positioning Results from P4 Post-Processor

DOES IT WORK?

A useful way of assessing the accuracy and precision of a GPS receiver is to carry out a 'zero baseline' test. This involves two receivers connected to a single antenna, independently recording measurements for later analysis. Since they share the same antenna, the derived baseline between the two receivers should be identically zero. The test is useful because a number of phenomena which contribute to errors in the raw measurements, such as atmospheric refraction, satellite ephemeris and multipath, should be common to the two receivers, and should cancel each other in the post-processing. The test therefore highlights the instrumental precision of the raw observables.

A zero baseline test has been carried out using two similar Garmin receivers, connected to a single low-cost antenna via an antenna splitter (Figure 4). In this case, the exercise is a good test of GRINGO's decoding abilities, since any errors made by GRINGO on one receiver would not be cancelled by independent errors made on the other receiver. One receiver logged RINEX data directly to a laptop computer, while the other logged the necessary raw data to a Psion PDA (Figure 5), and GRINGO was used to process the raw data into a RINEX file. The exercise was carried out over 10 minutes, with observations recorded at 1-second intervals.

Figure 4 - Zero Baseline Experiment

Figure 5 - Logging Data to a Psion PDA

Figure 3 illustrates the results achieved if one receiver is treated as a reference receiver and the other as a *mobile* receiver, ie each epoch of data is processed independently to give the *track* of the mobile. Since the shared antenna was static, each epoch of data should give the same (zero) result. The figure shows that the individual coordinate solutions for the mobile receiver have a mean of 1.1 m from the reference receiver, and that 95% of the results are within 1.4 m of the mean.

Figure 6 illustrates the results achieved if the second receiver is treated as *static*, ie every epoch of data contributes to a single overall coordinate solution from the second receiver. The figure shows how the solution converges to a final position as successive epochs of data are added. The final position was 0.9 m from the reference receiver.

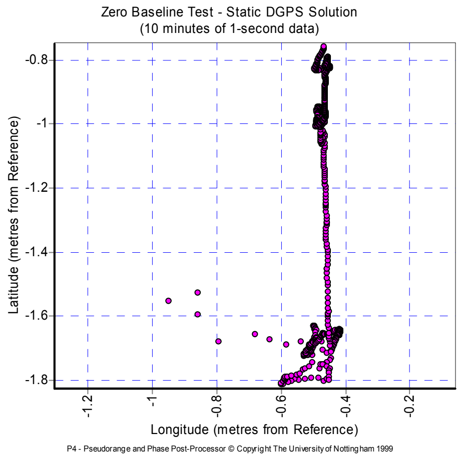


Figure 6 - Track of Accumulated Position

Figure 7 shows the pseudorange residuals from the static processing. The rms of all the residuals is 0.8 m, and since the 'noise' of both receivers is included in this figure, the precision of a single receiver can be calculated from this test as 0.6 m (0.8/√2).

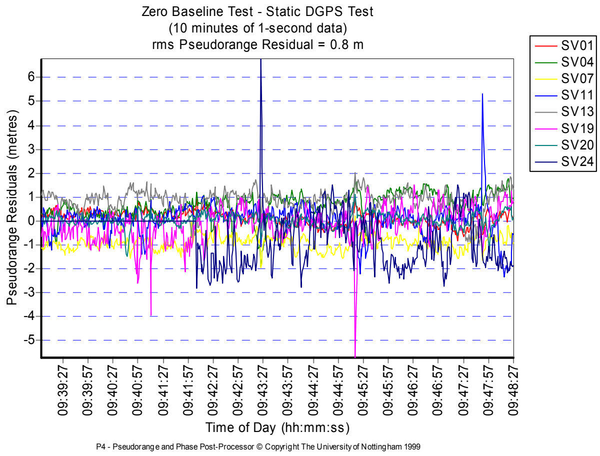


Figure 7 - Pseudorange Residuals from Static DGPS

Figure 8 shows the single coordinate solution from an ambiguity-fixed carrier phase solution of the 10-minute data span. The interesting feature of this plot is the fact that the distance between the two receivers has been measured as 0.1 mm. Figure 9 shows the corresponding double difference carrier phase residuals, which have an rms of ~0.02 cycles (~4mm). The precision of the raw carrier phase measurement can therefore be deduced as 4mm/2√2 = ~1.4 mm

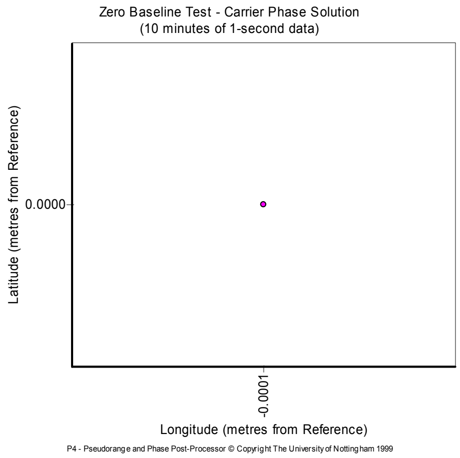


Figure 8 – Carrier Phase Solution

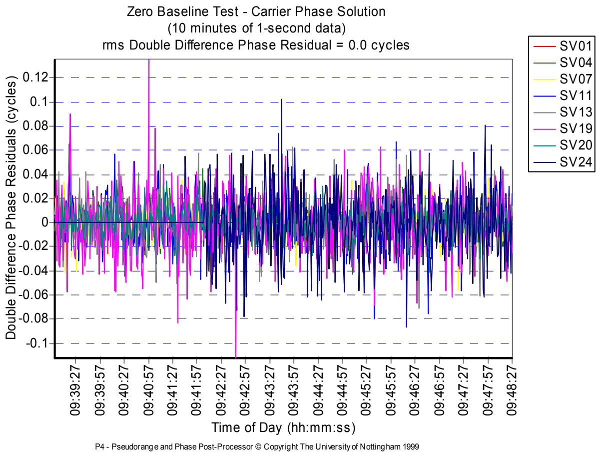


Figure 9 – Carrier Phase Residuals

SURVEY ACCURACY

It is clear from numerous tests that the Garmin receivers suffer from half cycle slips, and the initial ambiguities can also take half cycle values as a consequence. The cause of this is not known, but it is possible that the receiver uses a signal squaring approach to access the carrier. The unfortunate result is that software packages expecting integer ambiguities (for ambiguity fixed solutions) and whole cycle slips, will not cope well with Garmin data. Software which allows the ambiguities and cycle slips to 'float' may have more success, but they must still be able to detect half cycle slips if they are to allow them to float.

As an initial test of the accuracy that could be achieved if the ambiguities and cycle slips are allowed to float, an experiment was carried out between two Garmin 12XL receivers on a known 3.2 km baseline. The objective was to determine the span of data required to give reliable accuracies of a few cm or better over a typical short baseline.

One of the Garmin receivers was connected to a geodetic choke ring antenna, while the other used a simple cheap external antenna, designed for navigational use on a car roof, for instance. A period of 3 hours of 1-second data was logged, and the data was then processed in a number of shorter sessions:

- 18 consecutive 10-minute sessions
- 12 consecutive 15-minute sessions
- 6 consecutive 30-minute sessions.

Table 1 shows, against the start time of each processed session, the horizontal and vertical errors in the processed coordinates.

These tests indicate that 10 minute data spans can give horizontal and vertical accuracies better than 0.5 m, and 15-minute data spans can achieve better than 20 cm. The 30-minute data spans, with one exception (11 cm), give 5 cm or better.

	10-minute Sessions		15-minute Sessions		30-minute Sessions	
Start Time	Horiz (m)	Vert (m)	Horiz (m)	Vert (m)	Horiz (m)	Vert (m)
12:00	0.09	0.01	0.17	-0.02	0.03	0.01
12:10	0.39	-0.31	-	-	-	-
12:15	-	-	0.18	0.13	-	-
12:20	0.03	0.04	-	-	-	-
12:30	0.21	0.13	0.11	0.06	0.03	-0.02
12:40	0.05	-0.09	-	-	-	-
12:45	-	-	0.06	-0.02	-	-
12:50	0.16	0.06	-	-	-	-
13:00	0.16	-0.18	0.17	-0.10	0.04	0.00
13:10	0.10	0.07	-	-	-	-
13:15	-	-	0.02	0.04	-	-
13:20	0.07	0.06	-	-	-	-
13:30	0.08	0.09	0.02	0.04	0.05	0.03
13:40	0.12	0.06	-	-	-	-
13:45	-	-	0.03	-0.05	-	-
13:50	0.03	-0.08	-	-	-	-
14:00	0.11	0.09	0.02	0.03	0.11	0.00
14:10	0.01	0.13	-	-	-	-
14:15	-	-	0.11	0.00	-	-
14:20	0.11	-0.06	-	-	-	-
14:30	0.04	0.03	0.05	-0.04	0.00	0.00
14:40	0.21	0.04	-	-	-	-
14:45	-	-	0.11	-0.01	-	-
14:50	0.25	-0.07	-	-	-	-

Table 1 - Garmin carrier phase accuracy with short data spans and float solutions.

A simple semi-automatic process was coded to fix the ambiguities and cycle slips to their correct half cycle values, and the processing of the above sessions was repeated. The process was unable to reliably fix the ambiguities and slips using the 10- and 15-minute sessions, but worked reliably with the 30-minute sessions. The results of the 30-minute sessions are shown in Table 2.

The accuracy of each of the 30-minute sessions improved to approximately 1 cm, including the session which only achieved 11 cm in the float case. This improved accuracy is typical of ambiguity-fixed carrier phase solutions. Of course, the inability of the ambiguity fixing routine to fix the 10- and 15-minute sessions was probably the fault of the simple routine, rather than the data. It is probable that a more sophisticated search algorithm, if coded to cope with half integer ambiguities, would have more success with the shorter time spans, and thereby enable at least a fast static approach, if not a full real time kinematic (RTK) approach.

	30-minute Sessions	
Start Time	Horiz (m)	Vert (m)
12:00	0.007	0.007
12:30	0.006	0.002
13:00	0.009	0.016
13:30	0.011	0.001
14:00	0.010	0.003
14:30	0.008	0.014

Table 2 - Improved Garmin carrier phase accuracy with ambiguity-fixed solutions

RAPID MAPPING

A recent exercise with Gringo considered the rapid mapping of a site to produce a new orienteering map from scratch. The chosen site was the grounds of a conference centre which is set in about 1 square kilometre of parkland.

Orienteering is a sport that uses and develops the navigation skills of map reading, route choice, and dead reckoning by compass and pacing. A course visits a number of control points which are marked on a map and shown in the terrain by a red and white marker flag along with a device to prove the visit. The orienteer has to find the markers with only the map, a description of the control sites, and a compass. Competitively, the orienteer tries to complete his/her course in the shortest time but many take part recreationally.

The key component is the specially prepared map, usually at a scale of 1:10,000 or 1:15,000 although smaller scales are used for mountain marathons and larger scales for small areas, often school grounds, which are used as an introduction to beginners. There are a few professional orienteering mappers, however most maps are surveyed and drawn by amateurs.

The maps contain far more detail than would be found on an Ordnance Survey (OS) map. Included will be any features that can be used as a control site (e.g. boulders, pits, knolls, ditches, earth banks, re-entrants, spurs) or affect route choice (e.g. contours, density of vegetation, thickness of undergrowth). In terrain with a dearth of features the smallest items (e.g. 0.5m boulder) and every nuance of contour detail will be included, whereas if there is a wealth of features only the prominent items will be included.

As most orienteering is done in forests, runnable woodland is indicated by white and progressively denser vegetation by light to dark green indicating slow run, walk (e.g. closely planted young conifers) and fight (e.g. rhododendrons). Furthermore, undergrowth that impedes progress may be indicated by vertical green lines.

As the only navigation aid allowed in competition is a compass, there are no coordinates or grid lines on the map, just magnetic north lines. Absolute accuracy of scale and height is not important, but good relative accuracy is important.

Traditionally, orienteering maps are surveyed by filling in the detail on a good OS or photogrammetric base map. Unmapped woodland may be divided into blocks by first completing the ride, track and path network. Remaining large blocks are broken down by marking where linear features (e.g. ditches) cross rides and tracks on the base map and then following these features through the forest, tracing their route on the map between the earlier made marks. A similar process can then be carried out for all other linear features. Finally, the remaining point detail is located by reference to the previously mapped features.

The most sophisticated equipment available to the amateur surveyor is likely to be a sighting compass. Distance will normally be determined by careful pacing, although a measuring wheel is a useful aid on tracks and paths. Open areas, especially moorland, lend themselves to photogrammetry, nevertheless a field survey is still necessary to validate the photogrammetrist's interpretation and fill in any detail not visible on the aerial photograph.

GPS has not yet made a major contribution to orienteering mapping largely due to the cost of survey and/or DGPS systems or the inadequate accuracy of handheld receivers especially under the tree canopy or in deep valleys.

To survey the conference centre site for this exercise, the approach adopted was to walk around or along every area or line feature with a Garmin receiver, using Gringo to log the raw measurement data at 1-second intervals on an attached laptop PC (Figure 10).

Figure 10 – Field Equipment – Laptop, Receiver and Antenna (under Hat).

The aim was to process this data differentially against a nearby reference station. In order to provide 1-second reference data, and to minimise the distance from the reference station to the roving receiver, a temporary reference station was established in the car park of the conference centre, simply by placing another Garmin receiver inside a car (with an external antenna placed on the car roof), and logging raw data to another laptop, also at 1-second intervals (Figure 11). The coordinates of this temporary reference station were later determined by processing the recorded carrier phase data against the nearest Ordnance Survey active reference station, located in Nottingham.

Figure 11 – The Local Reference Station

In order to collect all of the features that should appear on the orienteering map, it was necessary to walk along footpaths, kerbs, fences (Figure 12), building walls, embankments and vegetation boundaries, and also to attempt to walk the boundaries of the overhead tree cover.

Figure 12 – Walking a Fence Line

To orientate the finished map (which does NOT have grid lines), a line on a constant magnetic North bearing was walked. At significant points in the route, the Garmin receiver's built-in waypoint marking facility was used to record, for instance, fence intersections, significant trees, and the start and end of each feature (Figure 13).

Figure 13 – Coordinating a Tree

While the surveyor was walking the necessary features, a companion took notes of the route walked, and also recorded the attributes of each feature and waypoint, so that the post-processed tracks could later be interpretted into a map. The entire field survey took a team of 4 people (two teams of two) approximately 5 hours to complete, although on this occasion it was a learning exercise, and this time could easily be reduced if necessary.

When processing the recorded tracks, phase smoothing was applied to the raw pseudorange data from both the roving receiver and the temporary reference receiver, to minimise the effect of random measurement errors.

Clearly, the receiving environment was not ideal in many areas of the survey. For instance, walking the perimeter of a discrete area of tree cover inevitably meant that a large part of the sky was obscured by the overhead foliage. Similarly, attempting to walk along the walls of buildings again meant that up to half the sky was blocked. An amount of experimentation was required with the post-processing software to get the best from the available data. For instance, a lower elevation mask angle than is usually applied was sometimes necessary, to counter the reduced number of satellites in difficult areas. Measurements with a low signal-to-noise ratio were excluded in some cases, in an attempt to reject measurements that had been affected by multipath. Nevertheless, despite these efforts, the accuracy of the resulting tracks was highly variable.

Figure 14 shows the track that was computed from the initial survey of the boundary of the grounds. The smooth tracks along the north-west boundary and down the fence line on the western perimeter (see Figure 12) are good examples of the results that can be achieved with a clear view of the sky. However, in the eastern half of the survey, where tree cover was the main problem, the results are much less accurate, with a significant number of off-track outliers.

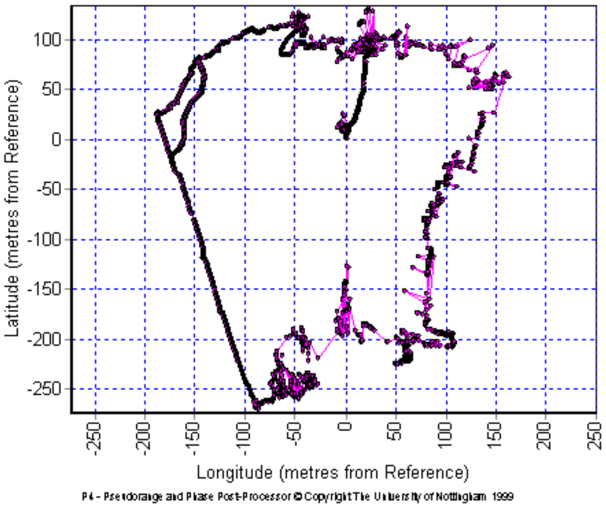


Figure 14 – Initial Boundary Survey

A particular problem occurred in picking up the perimeter of a tennis court in the middle of the site. The court was surrounded by a tall wire mesh fence along its perimeter. Figure 15 shows the results that were achieved in this area. It would appear that the fence has either masked the GPS signals completely, or created a severe multipath environment, such that the post-processing could only get results for a small section of the perimeter on the southern edge. It is notable that three points in the western boundary are clearly offset into the middle of the court, suggesting that some common error has affected the measurements at those three epochs.

Figure 15 also shows the boundary of the tennis court as depicted by the four waypoints recorded internally in the Garmin receiver. These appear to have produced a better representation of the tennis court than the post-processed results. It should be remembered that these waypoints are the result of the receiver's stand-alone solutions at those epochs, as the receiver did not have access to real-time differential corrections. It is accepted that the receiver uses a navigation filter of some sort as part of its position solutions, and it would appear that this internal filter is able to produce a sensible solution even when post-processing cannot, perhaps by enabling some internal 'data snooping' to eliminate poor quality (e.g. reflected) signals. The receiver's impressive ability to continue to provide a realistic solution in difficult conditions was seen in other parts of the data set as well. Of course, since this internal solution is not based on differential positioning, the absolute accuracy of the waypoints is not as good as the post-processed solution (when it works), and this can be seen as offsets between the waypoint solutions and the post-processed solutions, for instance along the southern perimeter of the tennis court (Figure 15).

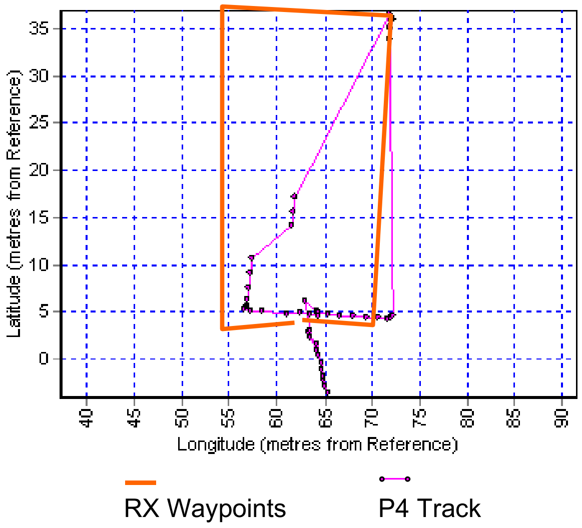


Figure 15 – Problems around a fenced Tennis Court

The production of the final map from the post-processed tracks took at least as many man-hours as the original field survey. Since the survey was completed in seven discrete logging sessions, there were seven separate post-processed tracks to interpret. Many features were straightforward to interpret from their shape and position, and the quality of the track. For instance, the fence line already noted in Figure 14 could be identified very simply. However, other features were less clear, due to a combination of the poorer quality track (e.g. under tree cover) and the fact that many features crossed or overlapped each other (e.g. footpaths under trees or across roads). To assist with the interpretation, the receiver's internal waypoints were used to split the track into many separate sections, each corresponding to a discrete segment, such as the start and end of a kerb line. This process was automated, using the time tags associated with the waypoints to split the tracks, but since the receivers only tag the waypoints to the nearest minute, the track disection was not precise. Nevertheless, with these smaller segments, and the necessarily brief notes that it was possible to make in the field, the components of the map were assembled piece by piece, using the OCAD software package.

Developed for orienteering, most maps are drawn using OCAD, a cartography application that has a predefined set of mapping symbols that meet the International Orienteering Federation's (IOF) standards. In addition to the normal range of drawing tools, the software can import both scanned images, to enable existing maps or survey material to be traced, and DXF files.

The adjusted coordinates, disected into segments between waypoints, and the Garmin waypoints themselves, were converted to DXF format for direct import into OCAD. A certain amount of interpretation and thinning out of the imported points was necessary, and once features were identified and located, it was usually possible to represent the features with a reduced number of points (e.g. the corners of buildings or the start and end of straight fence lines). The final map, including the control points of the orienteering course, is shown in Figure 16.

CONCLUSIONS

Gringo provides owners of Garmin 12-channel handheld receivers with a means of accessing raw measurement data. By post-processing these measurements in a differential mode with data from a reference receiver, coordinates with an accuracy of approximately 5 m can be computed from the pseudorange measurements, or better than 10 cm using the carrier phase measurements from a static receiver. An added benefit of post-processing is that full 3-dimensional coordinates are obtained. With stand-alone GPS, the height component is usually poorly determined, and most handheld receivers don't record it.

This paper has described how Gringo has been used to produce an orienteering map without recourse to a base map. This approach clearly has the potential to be used on a wider scale, but some lessons from this exercise will have to be addressed. Particular problems occurred, naturally, where GPS reception was impaired, such as under tree cover and alongside buildings. It is likely that a combination of techniques will prove more appropriate in these cases. For instance, around buildings Gringo could be used to provide accurate control points nearby, and more traditional techniques could be employed to adequately fill in the detail.

It is notable that the Garmin receiver often gave a more useful result than the post-processed solution in difficult observing environments. Work is currently under way in the IESSG to determine the most appropriate means of improving the post-processed solution in these cases, possibly by employing a filter in the solution to assist in identifying poor quality measurements. In addition, the interpretation of the final track proved to be a timeconsuming process, and various means of improving this are currently under consideration. These include modifications to the logging software that would allow pre-defined markers to be inserted into the RINEX data file as comments, to precisely mark the start and end of features for instance, and improvements to the processing software to automate the DXF production.

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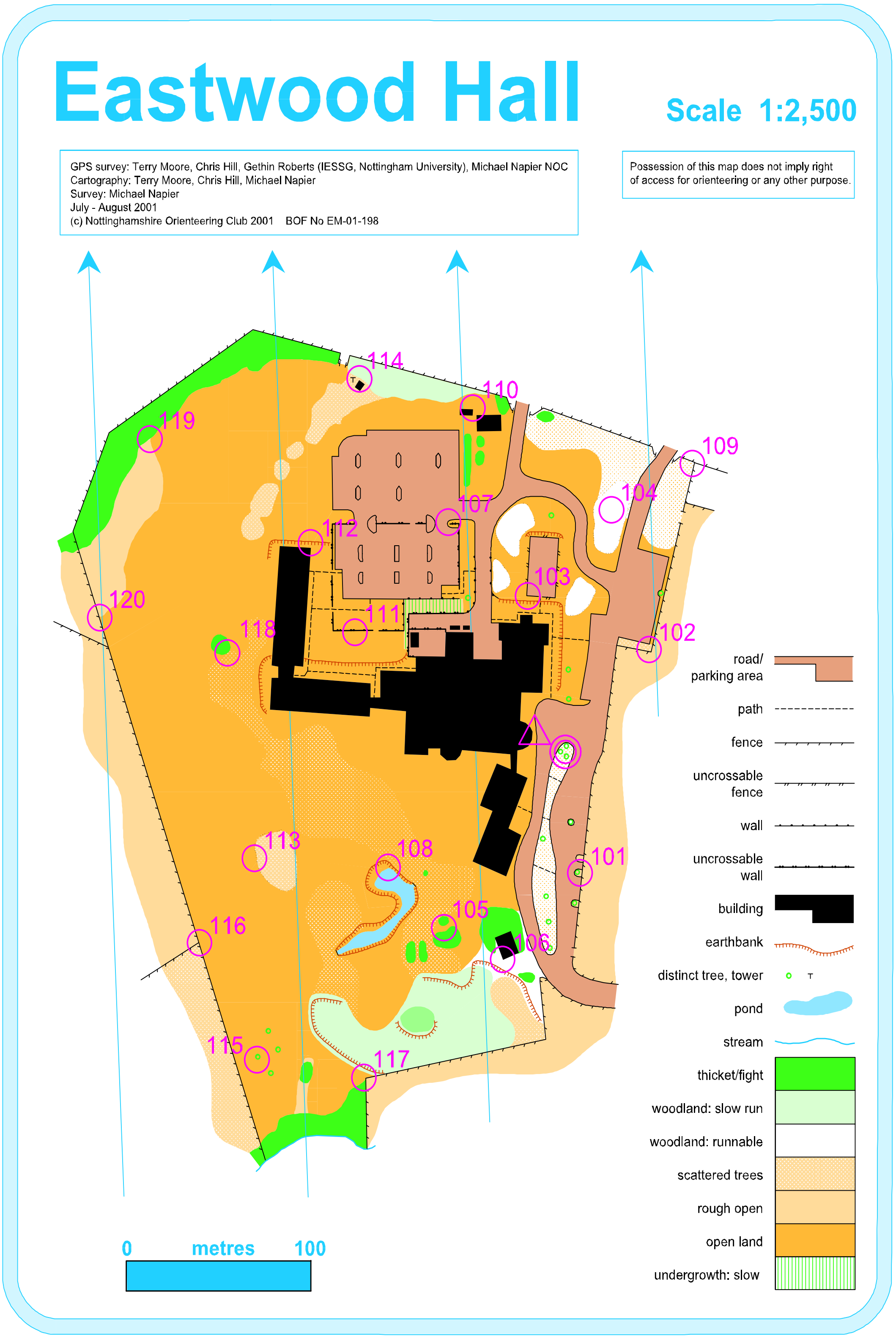

Figure 16 – The finished map (not at original scale of 1:2,500)