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Dynamic Non DGPS positional accuracy performance between recreational and professional GPS receivers.

Ger J Devlin, Kevin McDonnell, Shane Ward.

Biosystems Engineering Department, University College Dublin, Earlsfort Terrace, Dublin 2, Ireland.

Email of corresponding author: ger.devlin@ucd.ie Tel +353 1 716 7418. Fax +353 1 475 2119.

Email of author 2: kevin.mcdonnell@ucd.ie Tel +353 1 716 7472. Fax +353 1 475 2119.

Email of author 3: shane.ward@ucd.ie Tel +353 1 716 7351. Fax +353 1 475 2119.

Abstract

The purpose of this study was to measure and evaluate the dynamic non - differential positional accuracy of two Global Positioning Systems (GPS) receivers. The two receivers used were the Trimble GeoXT handheld and the Garmin GPSMAP 76. Both units are single-frequency, twelve channel GPS receivers. The units were tested for Horizontal Root Mean Square (HRMS) positional accuracy without real – time differential correction in the dynamic mode by recording the movements of an articulated truck across the Irish road network. The units were operated with their external magnetic-mounted antenna. The two antennas were fitted side by side to the cab of the truck. The articulated truck was a DAF XF95 model, 4*2 tractor unit with a tri-axle road-friendly air suspension Fruehauf curtain side trailer measuring 13.6metres (m) in length and 4.2 m in height from the ground.

Routes were travelled from the east of Ireland to the south and south–west of the country on six separate occasions during August 2005 giving a total of six consecutive routes. Over 50 hours of data, totalling approximately 6000 data points, sampled at 30 second intervals, were recorded for each of the GPS units. Of these 50 hours, over

30 hours were recorded as dynamic points, totalling approximately 4000 sampling points. The HRMS accuracy was measured at a confidence level of 63%. The HRMS results for the Trimble GeoXT ranged from about 6.9 m for the Cork 1 route to 3.2 m for the Cork 2 route (Table 1). Results for the Garmin GPSMAP76 varied from a much higher value of about 43.0 m for the Limerick 3 route to 56.9 m for the Cork 2 route (Table 1). With this highly variable level of positional accuracy between the two GPS units, it is clear which receiver unit can best be used for professional GPS data collection (Trimble GeoXT) and which is suitable for use as a recreational device (Garmin GPSMAP 76). The option to collect field data using inexpensive recreational GPS units may be sufficient for outdoor enthusiasts who simply require an occasional location fix of moderate (even uncertain) accuracy, but it is unlikely to be sufficient for the GIS professional who requires consistently accurate locations of objects, lines and polygons so that data layers can be overlayed within a GIS. A position fix that is tens of metres in error can lead to distorted spatial data and hence incorrect decision making. In fact, for some applications, a very inaccurate position could be worse than no position fix at all.

Keywords: Trimble GeoXT, Garmin GPSMAP76, GPS, differential GPS, dynamic positional accuracy.

1. Introduction

Within the Irish forestry sector (both private plantations and state owned) there is a necessity to introduce Information Technology (I.T.) into the timber haulage sector (Optilog, 2003). Specifically, Information Technology in this sector implies the use of GPS for tracking of timber trucks from a forest harvesting site to sawmill destination, and the incorporation of this positional information within Geographical Information Systems (GIS) to determine if the truck is located at the harvesting site, travelling on a national route or unloading within a sawmill (Frisk et al. 2005). Precision forestry is rapidly becoming an important practice, involving many aspects such as timber harvesting within the forests and subsequent timber transportation on both internal forest roads and the public road network. High GPS positional accuracy for internal forest applications is a prerequisite for updating the GIS forest roads database.

This paper documents the results of the performance testing of non-differential GPS (DGPS) techniques using both the Trimble GeoXT and the Garmin GPSMAP 76. Both receivers were used to track an articulated truck across public roads in Ireland. The results show that a recreational GPS receiver was not capable of providing the accuracy necessary for the GPS tracking of trucks travelling across the Irish road network, and definitely not adequate for mapping the internal forest roads. Further research will involve the tracking of the articulated truck on the internal forest road network. This will allow the mapping of any unknown forest road from the recorded GPS data and its transfer into a GIS forest roads map layer. The authors have tested two GPS receivers in an open environment and are confident that the Trimble GeoXT, with its EVEREST multipath rejection technology, option to use the EGNOS correction overlay service, and ability to operate in DGPS mode), is well suited for generating a high level of positional accuracy in the forest canopy environment. The eventual plan will be to create and update the internal forest roads database for different forest compartments. This will allow the X and Y co-ordinates of harvested timber stacks to be entered on the GIS map and be easily located by the truck driver.

2. Materials and Methods

2.1 GPS – background

The Global Positioning System (GPS) consists nominally of 24 satellites orbiting the earth at an altitude of approximately 20,000 km (at the time of writing in February 2007 there are in fact 30 satellite in orbit). GPS satellites broadcast radio signals on two different frequencies, the L1 = 1575.42 MHz and the L2 = 1227.60MHz. Each signal contains a digital code, the Precise “P” code and the Civilian Access “C/A” code. The P code is transmitted on both frequencies but scrambled by the US DoD for security reasons under a policy known as “anti-spoofing”. With a single receiver the P code allows geographical locations to be determined with metre-level accuracy. The C/A code is broadcast on the L1 only and available to any civilian GPS user as part of the Standard Positioning Service (SPS). (A detailed description of the GPS, its signals, and positioning principles is beyond the scope of this paper and readers are referred to an excellent range of GPS reference books at the online bookshop NavtechGPS, 2007, and official literature and status reports on GPS available from the U.S. Coast Guard’s NavCen website, NavCen, 2007.) SPS receivers can determine position, velocity and time (PVT). The P and C/A codes contain signal transmission timing data that the GPS receiver uses to determine how long it takes the signal to travel from the satellite to the receiver. Since radio signals travel at the speed of light (299,792.458m / sec), the distance between the satellite and the receiver is simply the transmission time multiplied by the speed of light. This calculation must be very precise in order to obtain accurate positions. Three satellites are necessary for a 2-dimensional position fix, with two satellites needed for determining horizontal position and the third satellite for determining the receiver clock error, with the height constrained to a known or average value. Threedimensional positioning requires three satellites for determining the 3-D coordinates, with the fourth satellite used for determining the receiver clock error. The clocks within GPS receivers are not as accurate as the satellite atomic clocks and it is for this reason that the receiver clock error must be continually determined as part of the position fix calculations. (In fact a GPS receiver, after a position fix, is the most accurate portable clock ever built, giving absolute time to sub-microsecond accuracy.) Differential GPS (DGPS) is an advanced GPS technique that cancels out any errors associated with satellite clock timing errors and atmospheric refraction effects. DGPS involves running a reference receiver at a known location to calculate the satellite timing and atmospheric errors and to then relaying these as corrections to the roving GPS receiver for enhanced positional accuracy, in real - time.

Not all receivers that use differential corrections flag their solution coordinates with the correction status, hence it is impossible to distinguish between the corrected data and the uncorrected data in some cases. This is not an issue with more advanced professional receivers, which provide additional information about each position fix. This data about GPS data is known as *metadata.* Metadata provides information about the GPS PVT fix such as date, time, dilution of precision (DOP), speed, the datum in which the coordinates were transformed, and other information. The recorded coordinates can also be used with Environmental Systems Research Institute's (ESRI's) Tracking Analyst extension for ArcMap. This extension software allows the playback of GPS recorded data. Features such as GPS quality control, electromagnetic shielding, antenna technology, quality of the housing and user interface, size of screen and onboard memory are just some of the design features that may distinguish a professional receiver from a low-cost recreational receiver.

The Trimble GeoXT and Garmin GPSMAP 76 used for this experiment are twelve-channel, SPS (L1-only) GPS receivers. They were both used in the non - differential mode to determine how accurate the positions of an articulated truck travelling across Irish roads could be determined. The recorded data showed that a maximum of nine satellites and a minimum of four satellites were tracked during the experimental period, which implies that good quality GPS position fixes should be possible (Prisley et al. 1995). Both GPS receivers were used with external magnetic antennas fixed side by side to the roof of the cab of the truck. An external antenna can significantly improve the signal strength in difficult environments, which consequently results in a higher number of positions recorded and less degradation of the signal and positional accuracy.

2.2 Software and data used

The GIS used in this research is ESRI's Arcview 8.3 (ArcCatalog, ArcToolbox and ArcMap) to explore, query and analyse the data geographically. The development platform was Windows XP for PC's. The main tools used to create, manage and edit the geodatabase are found in ArcCatalog and ArcMap. ArcCatalog has the tools for creating and modifying the geodatabase schema while ArcMap is used to analyse and edit the contents of the geodatabase.

The Trimble GeoXT handheld receiver can provide sub-metre accuracy in real-time through space-based augmentation systems such as WAAS (North America) and EGNOS (in Europe only) and DGPS. However, the results of this paper attempt to quantify the HRMS dynamic positional accuracies of both the Garmin GPSMAP76 and the Trimble GeoXT *without* DGPS correction. The GeoXT receiver includes EVEREST multipath rejection technology for optimal performance in difficult GPS environments. Multipath occurs when the signal picked up by the GPS antenna has been reflected off a surface (in this case, the top of the trailer or the wind – deflector on the roof of the cab), rather than being received directly from the GPS satellite. Because the signal has been delayed, it introduces errors into the position calculation, therefore reducing the accuracy performance of the GPS. Antenna technology is one of the key methods to reduce multipath and to bolster signal strength. The GPS data was recorded through the ESRI ArcPAD software on the GeoXT. The GPSMAP 76 records its positions through connection to a PDA via the HGIS (StarPal) software version 7.25. This requires a cable connection to the PDA, which has a poor battery life, especially when recording GPS data.

The data was recorded in the World Geographic System 1984 (WGS84) datum, i.e. the GPS reference frame. Since the digital road map data is in Irish National Grid (ING) form, the GPS data had to be transformed into the Irish National Grid reference frame (Ordnance Survey Ireland, 1996; Ordnance Survey Ireland, 1999; Bray, 2001). As well as this, WGS84 records the latitude and longitude in decimal degrees. In order to compare the accuracy of the GPS data with the underlying road vector network in units of metres, each GPS data point was to be converted from WGS84 decimal degrees to Eastings and Northings of the Irish National Grid in metres. This data conversion was carried out with Grid Inquest 6.0 software, which is available from the Ordnance Survey Ireland website (Quest Geodetic Software Solutions Ltd). Map projection onto the Irish National grid was necessary in order to eliminate alignment and accuracy errors when adding the layers of GPS route data for eventual analysis within the GIS (Ordnance Survey Ireland, 2000; Ordnance Survey Ireland, 2001). This projection of coordinate systems was carried out within ArcCatalog. The digital road network of Ireland was used within the GIS, which comprised motorway, national primary, national secondary, and regional and third class roads. The road network was represented as connections of 5917 nodes and 8941 links together. The nodes represent the road intersections and the links represent homogeneous road segments. Geometric networks are built in the GIS model to construct and maintain topological connectivity.

2.3 Data collection procedure and study area

The experiment involved the truck travelling two main routes across the whole of Ireland, on different occasions throughout the month of August 2005. Each route was travelled three times from the haulage depot in the east of the country to two destinations in the south and southwest of the country (Figure1).

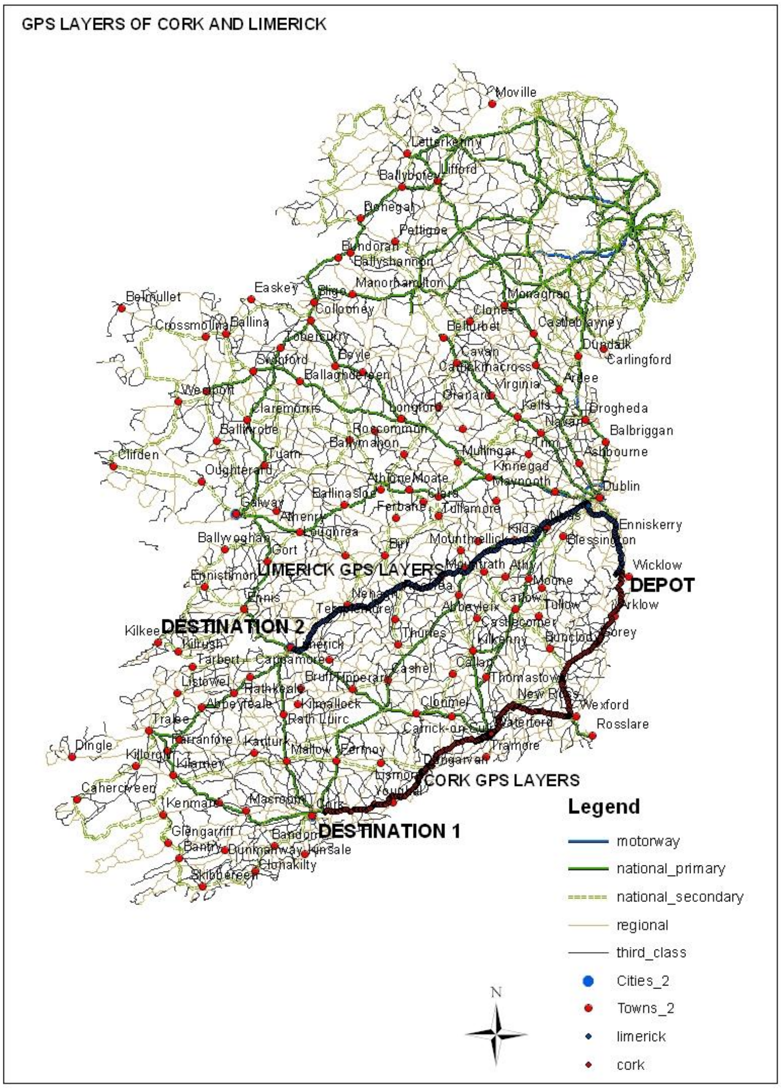

Figure 1. Digital road map of Ireland showing GPS routes to Limerick and Cork.

The GPS receivers were set to record data every thirty seconds along the route. Each route averaged a total of 1000 sample points, but averaging 650 dynamic sample points. There was on average seven satellites acquired for each sample point recorded (a maximum of nine satellites and a minimum of four satellites). The GeoXT can also record data as a shapefile (.shp), which allowed easy transfer of data between GPS and the ESRI ArcView GIS software installed on the laptop. The same method of data transfer applied to the GPSMAP 76. Data can be transferred using Microsoft's Active Sync. Dilution of precision values are influenced solely by the geometry of the satellites. Low values of Horizontal Dilution of Precision (HDOP) mean high precision, which in turn implies increased accuracy of the recorded data if there are no systematic biases affecting the measurements (Table 1).

3. Results and Discussions

3.1 Measuring Accuracy

Over 50 hours of data, totalling approximately 6000 data points were recorded at 30-second sampling intervals under open sky conditions by both the Trimble GeoXT and Garmin GPSMAP 76 (that is, about 100 hours of data totalling approximately 12000 data points). Of these 50 hours, over 30 hours were recorded as dynamic points, totalling approximately 4000 sampling points for each receiver. The tests were carried out across two separate routes, each route being travelled three different times during August 2005.

The objectives of these tests were to determine:

1). How accurate are the sampled points in relation to the underlying road vector network.

2). How does the non-DGPS positional accuracy of both GPS receivers compare to each other.

From within the GIS, the data recorded from each route can be added as a shapefile (.shp) layer to the map (Figure 1). The map contains the underlying road network in

Irish National Grid (ING) coordinates. The GPS points are converted from the WGS84 datum into ING in order to correctly overlay and align with the road network. Using GIS tools, a spatial join was carried out. This implies calculating how close each GPS point is to the underlying road vector. To measure accuracy, it is necessary to compare a known and unknown location. If there is no known location then only *precision* can be quantified. In this experiment, the known location is assumed to be the road network. The distance of the GPS fix from the known location was then calculated. From the statistics tools within the GIS, the mean and the standard deviation of the distance values between the recorded GPS points and the underlying road vector data can be calculated accordingly for each of the six specific routes. The root mean square is determined from the square root of the sum of the squares of the mean and standard deviation. This calculation is repeated for each route recorded by both of the receivers, i.e. six routes for the GeoXT and six routes for the GPSMAP 76. The results of the HRMS accuracy are shown in Tables 1 and 2.

The accuracy is expressed as a Horizontal Root Mean Square (RMS) value and is a measure of the spread of data around the known location. The HRMS value represents the horizontal distance from the known position on the road network and it defines the distance within which 63% of the position errors will fall.

Another related accuracy specification is 2dRMS or twice the distance HRMS. The confidence level for 2dRMS is 95%. A third accuracy specification is Circular Error Probable (CEP), which has a 50% confidence level. These three different measures can be used to describe a GPS receiver’s accuracy. They all describe the same spread of errors, but in different ways.

From Table 1 and Figure 2 it can be seen that the results of the accuracy of dynamic non–differential GPS prove quite favourable to the GeoXT, with a minimum HRMS accuracy of about 6.9 m for the Cork 1 route and a maximum HRMS accuracy of 3.2 m for the Cork 2 route. The GPSMAP 76, however, resulted in a minimum HRMS accuracy of about 43.0 m for Limerick 3 and a maximum HRMS accuracy of 56.9 m for Cork 2. It is worth noting that: 1) the width of the truck is approximately 2.5 m, 2) the total length of the truck and trailer is approximately 16.75 m, 3) the lane widths of a motorway are 3.5 m with hard shoulders, 2.5 m in width, and 4) the centre median is a minimum of 4.0 m. The same dimensions apply for dual carriageways. Single lane roads have a total range width from approximately 5 m to 8 m. (National Roads Authority). This implies a very high level of accuracy for the Trimble GeoXT GPS but not as impressive a performance for the GPSMAP 76.

The HDOP (2-D) values are also indicators of the quality of the GPS position. This value takes into account each satellite's location relative to the other satellites in the constellation and their geometry in relation to the GPS receiver. A low HDOP value indicates a higher probability of accuracy. The HDOP values recorded for each of the routes are summarised in Table 2 and correspond with those predicted from Trimble's satellite almanac 'Mission Planning Software' for each separate recording date (Trimble Mission Planning Software - Table 2 and Figure 3). The GPSMAP 76 does not provide any information regarding any DOP values, hence no comparisons can be made with the HDOP values recorded by the GeoXT.

	DATE	TRIMBLE GeoXT (m)	GARMIN GPSMAP 76 (m)	MAX SATS	MIN SATS
Limerick1	11/08/05	5.2734	45.9426	9	5
Limerick2	15/08/05	4.393	45.4082	9	5
Limerick3	16/08/05	6.8017	43.024	9	5
Cork 1	25/08/05	6.9197	54.8437	9	4
Cork 2	26/08/05	3.1926	56.9076	9	4
Cork 3	29/08/05	4.303	56.4808	9	5

Table 1. Summary of HRMS positional accuracy for single receiver (i.e. non–differential) GPS across each of the six routes for the Trimble GeoXT and Garmin GPSMAP 76.

	DATE	HRMS (63%)	MEASURED HDOP	TRIMBLE HDOP	GeoXT MAX SATS	GeoXT MIN SATS	TRIMBLE MAX SATS	TRIMBLE MIN SATS
Limerick1	11/08/05	5.2734	1.375	1.364	9	5	9	5
Limerick2	15/08/05	4.393	1.173	1.448	9	5	9	5
Limerick3	16/08/05	6.8017	1.335	1.369	9	5	9	6
Cork 1	25/08/05	6.9197	1.389	1.537	9	4	9	5
Cork 2	26/08/05	3.1926	1.306	1.485	9	4	9	6
Cork 3	29/08/05	4.303	1.298	1.552	9	5	9	5

Table 2. Summary of mean measured HDOP (GeoXT) Vs Trimble Planning Software mean HDOP values.

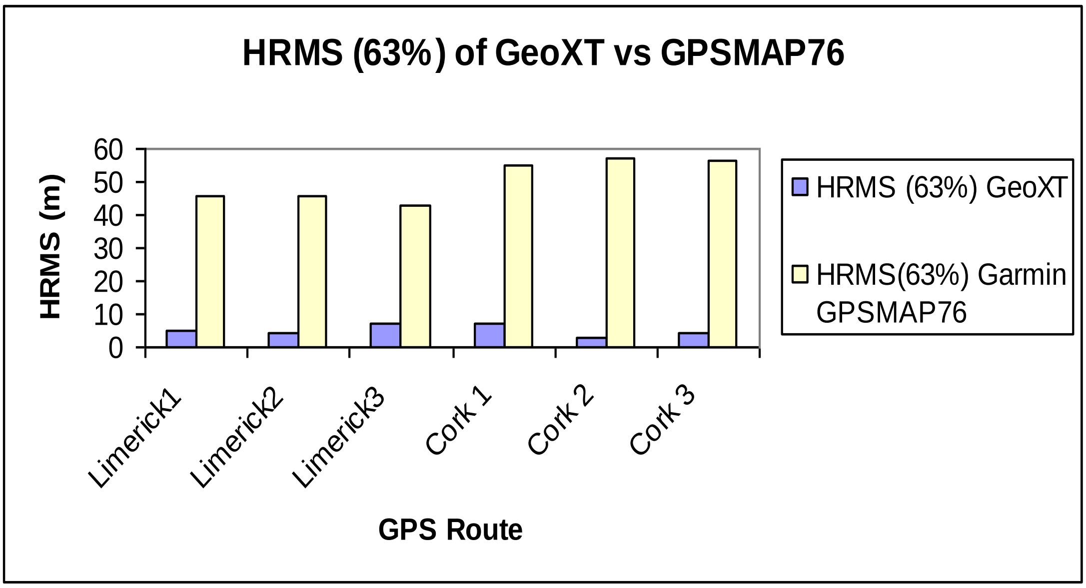

Figure 2. Graph of HRMS (63%) of Trimble GeoXT Vs Garmin GPSMAP 76.

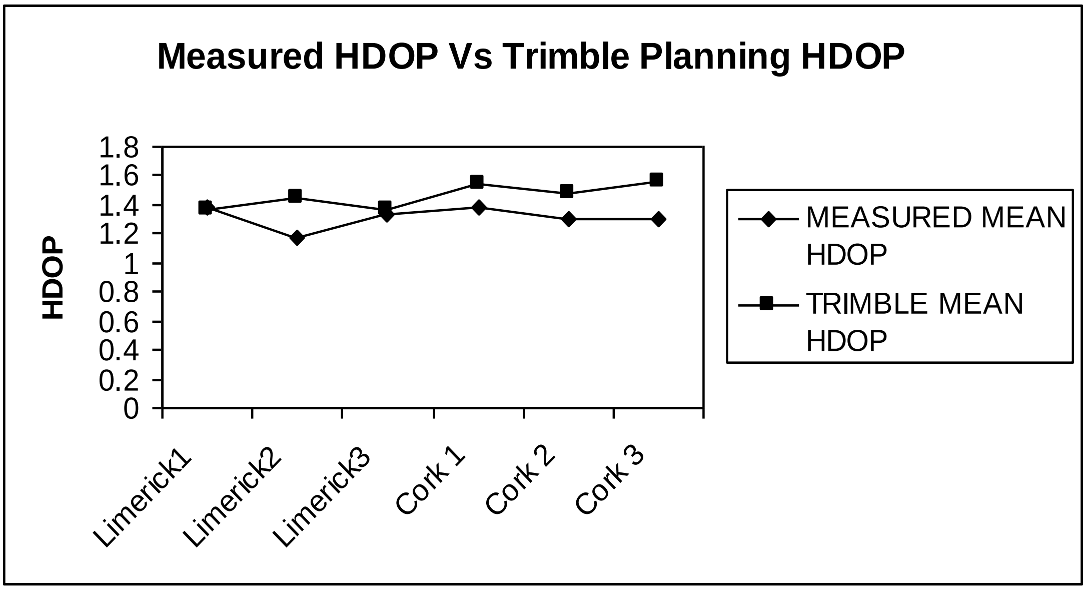

Figure 3. Graph of Measured HDOP (GeoXT) Vs Trimble Planning Software HDOP.

4. Conclusion

From this study of the dynamic performance of two GPS receivers, the Trimble GeoXT clearly demonstrates increased positional accuracy compared to the Garmin GPSMAP 76 receiver when both run in non-differential mode. There is no direct evidence to suggest that Trimble's antenna technology and the advanced EVEREST multipath rejection technology played a pivotal role in ensuring high accuracy. However, by rejecting the multipath signals before computing positions, the GeoXT would be expected to offer increased HRMS accuracy compared to the GPSMAP 76. Of course the performance of the GeoXT compared to the GPSMAP 76 cannot be solely attributed to the more advanced GPS technology within one receiver. Other factors such as atmospheric refraction effects, satellite ephemeris and clock errors and the dilutions of precision also impact on the final results. Ephemeris and clock errors, for example, can introduce errors in the range of approximately 2.5 m and 2 m respectively. Propagation delays in the troposphere and ionosphere can introduce errors ranging from approximately 2.5 m at the zenith and increasing to 28 m at the horizon. However, both receivers would have been influenced by the same external effects, and although they affect absolute accuracy, the GeoXT is clearly more accurate than the GPSMAP 76 in a "relative" sense.

This positional technology can monitor the movement of the trucks on the agreed routes for timber extraction and impose any penalties if these routes are not followed. Security of the timber can be increased by tracking the exact movement of the truck from harvesting site to destination mill, and identifying any unexplained stops that could indicate timber removal for personal gain. Back-loading of trucks can be implemented more efficiently by determining which truck is closest to the pick–up point and diverting it accordingly. In an environment where operating costs are rising continuously, the timber haulage sector must implement such technology in order to remain competitive and to maximise the time a truck is travelling while loaded. The next part of the research will involve using the Trimble GeoXT for in-forest GPS mapping of any unknown forest roads, and the updating of the GIS roads database accordingly.

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