Performance Accuracy of Real-Time GPS Asset Tracking Systems for Timber Haulage Trucks Travelling on Both Internal Forest Road and Public Road Networks

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ABSTRACT

The GPSTRACK project has arisen as a result of a recommendation in the Forest Industry Transport Group (FITG) Code of Practice for Timber Haulage, which was to "Encourage closer co-operation between consignors and hauliers to plan routes in a manner which optimizes the economic returns within a legal framework." The project involved the installation of Bluetree global positioning systems (GPS) asset tracking systems onto two timber haulage trucks: an articulated Iveco Stralis 530 6*2 tractor unit with tri-axle road friendly air suspension flatbed trailer with a design gross vehicle weight (dgvw) equal to 44 t and a Scania 124 (400) with a rigid (3 axle) + trailer (3 axle) + crane combination with an equivalent dgvw of 44 t. This paper discusses the background and use of real-time asset tracking devices in the context of timber haulage in Ireland. Real-time location information is a relatively new concept for Irish applications (less than 5 years), but there is an increasing deployment of the technology into the truck transport sector in Ireland. The goal of this study was to test the accuracy of the recorded GPS locations relative to the underlying travelled route network based on the criteria of: 1) a fixed GPS receiver location, 2) a truck travelling on public routes, and 3) comparing accuracy of public routes to the accuracy of the truck travelling in a more demanding environment such as the internal forest road network. The results analysis calculated the horizontal root mean square (HRMS) 63 percent GPS accuracy of both trucks tracklog on both the public road network and the internal forest road network over a period of 4 weeks which totalled approximately 15,000 GPS data points. The HRMS accuracy values ranged from 2.55 to 2.47 m for the public roads, while the forest road accuracy were approximately 27 m and 41 m for Iveco and Scania, respectively.

Keywords: *real-time GPS, asset tracking, HRMS 63% accuracy, public roads, forest roads, timber haulage*

Introduction

Since the deployment of the first of 24 satellites by the U.S. Department of Defense (DoD) in 1978, global positioning systems (GPS) have become a useful tool in forestry management with a need to geo-reference spatial information in terms of estimating forest road surveys (Martin et al. 2001, Holden et al. 2002), extraction of timber logs (Ronnqvist 1999), transport control of forest fuels (Sikanen 2005), and clarifying GPS performance under forest canopy and on industrial peat bogs (Holden et al. 1999, Holden et al. 2001).

Within the Irish forestry sector (both private plantations and state owned), there is a necessity to introduce information technology (IT) into timber haulage (Optilog 2003). Information technology in this situation implies the use of GPS for tracking of timber trucks from a forest harvesting site to sawmill destination, and incorporating this positional information within geographical information systems (GIS) to reference, for example, the timber truck on a map, 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 (Devlin et al. 2007a). High GPS positional accuracy for internal forest applications can be used for updating the GIS forest roads database to assist in avoiding time consuming and erroneous digitizing from paper maps.

Research has been conducted in an attempt to determine the effects of forest vegetation on GPS signals. Errors in a GPS signal occur due to the atmosphere (as the signal passes through the charged particles of the ionosphere and then through the water vapor of the troposphere). The signal can also bounce off of local obstructions on the Earth's surface before it reaches the receiver; in this situation the local obstruction is the vegetation and canopy of the forests. This is known as multipath error (when a signal arrives at a receiver through two or more paths) and the cause of inaccurate position fixes of the tracked machines. Spruce et al. (1993), using a typical mapping-grade GPS receiver, reported that the GPS successfully tracked forest machines under open sky conditions, but under forest canopies there were major decreases in accuracy. Also, Jalinier and Courteau (1993) attempted to economically survey forest road networks by traversing forest roads with a vehicle fitted with a GPS receiver, but concluded that areas with thick forest cover

yielded questionable results when compared to traditional methods of accurate surveying.
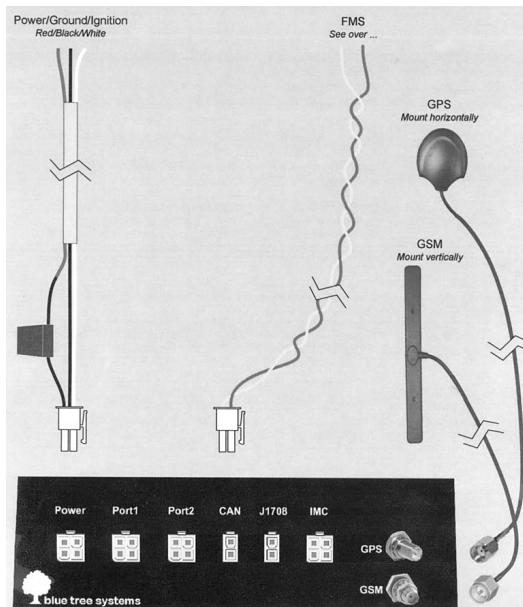
This paper documents the GPS performance accuracy of real-time asset tracking systems for timber haulage trucks travelling on both the internal forest road network and the public road network of Ireland and attempts to quantify the performance differences under varying canopy environments. The GPS accuracy is determined as a measure of horizontal root mean square (HRMS) at a confidence level of 63 percent.

Materials and Methods

Installation of GPS Hardware

The independent GPS asset tracking provider was the company Bluetree. Installation of the GPS Blackbox with GPS tracker takes approximately 30 minutes to complete and is almost equivalent to the installation of a hands-free mobile phone carkit. The Blackbox and associated wiring is fixed under the dashboard on the passenger side of the truck (**Fig. 1**).

The GPS tracker is positioned on the inside of the dashboard if it is plastic. If the dashboard is steel, then it must be positioned outside of the dashboard so that it becomes visible through the front windshield. Most transport managers require that the GPS receiver be placed inside the dashboard as they do not wish their drivers to know they are being monitored. The majority of managers in Ireland today are very concerned with their drivers' performance. The Global System for Mobile Communications/General Packet Radio Service (GSM/GPRS) magnetic antenna is fixed to the inside of the windshield for optimum signal strength. The GPS Blackbox is fitted with a standard mobile phone subscriber identity module (SIM) card and positional latitude and longitude information are recorded by the GPS and sent via the GSM/GPRS phone network to the data servers. This information can then be viewed through PC/laptop and Internet web browser with username and password through the login page of the asset tracker providers. The amount of updated data depends solely on the time interval required by the user. This system operated at 3-minute intervals but any time interval can be requested and set-up by the provider.

Truck Specifications

The Bluetree systems were fitted to two different axle configuration timber haulage trucks. The articulated truck was an Iveco Stralis 530 6*2 tractor unit with tri-axle road friendly air suspension flatbed trailer with a design gross vehicle weight (dgvw) equal to 44 t (**Fig. 2**). The Scania 124 (400) was a rigid (3 axle) + trailer (3 axle) + crane combination with an equivalent dgvw of 44 t (**Fig. 3**). Although both truck configurations have the same dgvw due to the 6-axle configuration, the articulated Iveco has a higher payload weight than the Scania rigid simply because this rigid + trailer + crane combination increases the tare weight and thus reduces the payload weight acceptable under weight legislation in Ireland. The on-board crane offers flexibility to the driver when loading and unloading timber. Also, some crane technologies allow the weighing of timber on each lift when loading, therefore enabling an approximate mea-

Figure 2. ~ *Iveco Stralis 530 articulated configuration.*

**Figure 3.** ~ *Scania 124 (400) rigid + trailer + crane configuration.*

Figure 1. ~ *Schematic of GPS Blackbox wiring from Bluetree (FMS wiring is included here but is not needed for Fleetmatics).*

sure and optimization of the payload weight to within 500 kg. This weighing facility is an added extra to basic timber crane functionality and costs in the region of €5,000.

Software and Data Used

The GIS used to explore, query, and analyze the data spatially is ESRI's Arcview 9.1 (ArcCatalog, ArcToolbox, and Arc Map). Within the ArcGIS desktop software family are ArcView, ArcEditor, and ArcInfo. ArcView provides data visualization, query, and analysis capabilities. ArcEditor has higher functionality than ArcView within its powerful data creation and editing environment. ArcInfo includes all of the functionality of both ArcView and ArcEditor and adds advanced data geoprocessing and data conversion capabilities that gives ArcInfo the highest GIS functionality within the desktop ArcGIS. The development platform was Windows XP for PCs. 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 analyze and edit the contents of the geodatabase.

The data was recorded in the Irish National Grid (ING) datum in decimal degrees of latitude and longitudes (i.e., the asset tracking provider's GPS reference frame). Because the digital road map data within the GIS is in the ING datum in meters of Eastings and Northings, the GPS data was converted from decimal degrees into meters (Ordnance Survey Ireland 1996, Ordnance Survey Ireland 1999, Bray 2001). This procedure is necessary in order to define the HRMS accuracy of the GPS data with the underlying GIS road vector network in units of meters. All of the data layers in the GIS must have the same coordinate systems (Irish National Grid) and the same units of measurement (meters). This data conversion was carried out with Grid Inquest 6.0 software, which is available as a free download from the Ordnance Survey Ireland website (Quest Geodetic Software Solutions Ltd.). The digital road network of Ireland was used within the GIS. This is comprised of motorway, national primary, national secondary, regional, and third-class roads. The road network was represented as connections of 5,917 nodes and 8,941 links. 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.

Results and Discussions

The study was carried out over a 4-week period in which 10,669 data points were recorded for the Iveco and 9,500 data points recorded for the Scania. After filtering both sets of data for raw GPS X and Y coordinates, the amount of workable data to determine HRMS accuracy becomes 8,360 data points for the Iveco (**Fig. 4**) and 5,049 data points for the Scania (**Fig. 5**). The data filtered was FMS engine diagnostic data that is irrelevant to calculating GPS accuracy. It is important to note that the GPS tracklog for each truck cannot be accessed or downloaded by the user once logged onto the system itself. This data is stored on the Bluetree data servers and must be requested from technical support for each truck. The file can be sent as a

Figure 4. ~ *Iveco Stralis public and forest road GPS tracklog created in GIS.*

Figure 5. ~ *Scania public and forest road GPS tracklog created in GIS.*

.txt file via email and thus can be imported to a Microsoft Excel© format and the GPS data filtered accordingly.

From within the GIS, the data recorded from each route can be added as a shapefile (.shp) layer to the map (**Figs. 4 and 5**). The map contains the underlying road network in ING coordinates. The GPS points are converted from decimal degrees latitude and longitude into ING meters in order to correctly overlay and align with the road network.

Table 1. ~ *HRMS 63% accuracy of public and forest road.*

Routes	Standard deviation	Mean	Positional accuracy Max.	Min.	(mean)2 + (sd)2	HRMS (63%)
Iveco forest road <100 m	21.28	17.11	100.00	0.03	745.47	27.30
Iveco forest road < 50 m	12.17	11.58	50.00	0.03	282.26	16.80
Iveco public road < 10 m	2.61	3.54	10.00	0.01	19.36	4.40
Iveco public road < 5 m	1.42	2.13	5.00	0.01	6.54	2.56
Scania forest road <100 m	28.00	29.95	100.00	0.28	1681.11	41.00
Scania forest road < 50 m	13.79	17.64	50.00	0.28	501.12	22.39
Scania public road <10 m	2.80	3.75	10.00	0.01	21.94	4.68
Scania public road < 5 m	1.40	2.05	5.00	0.01	6.15	2.48

Within the tools of the GIS, a spatial join was carried out on both the internal forest road network and public road network separately (**Table 1**). This implies calculating how close each GPS point is to the underlying road vector. To measure accuracy, it is necessary to have a known location. If there is no known location then precision can only be quantified. In this study, the known truth location is 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. The root mean square (RMS) is determined from the square root of the sum of the squares of the mean and standard deviation (SD). This calculation is repeated for varying buffer distance zones of 5 m and 10 m for public road HRMS and 50 m and 100 m for forest road HRMS. Research has previously shown that the HRMS 63 percent of dynamic GPS data on public roads is less than approximately 10 m, hence justification for these limits (Devlin et al. 2007b). The increased distance buffer zones for forest road analysis of 50 m and 100 m are indicative of the degradation of GPS accuracy under certain forest canopy conditions. Optimum GPS signal accuracy under forest canopy conditions would be increased with external GPS antennas. One of the main goals, however, was to assess how well the GPS antenna can perform from its position underneath the dashboard of the truck. This is the realistic location for the antenna and GPS blackbox since most transport managers install tracking devices unknown to the driver that need to be concealed to avoid any tampering. Again, the authors must stress that these devices are not just for real-time location information. If used and monitored correctly, these devices are used to control and reduce running costs of truck fleets in terms of driver working hours, driver performance, and monitoring theft of diesel fuel. Siphoning diesel fuel from the truck for drivers who drive the truck home is a serious cost issue for transport managers in Ireland; this system can help monitor that.

As mentioned previously, the accuracy is expressed as a RMS and is a measure of the spread of data around the known location HRMS. The RMS value represents the horizontal distance from the truth (road network) for which 63 percent of the position errors are predicted to be less.
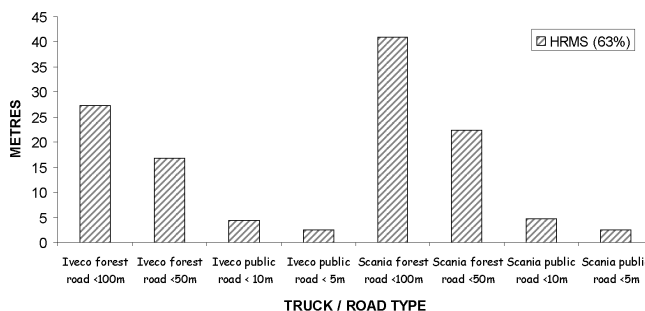
Figure 6. ~ *Graph of HRMS 63% accuracy for public and forest roads for Iveco and Scania.*

Another related accuracy specification is 2dRMS or twice the distance RMS. The confidence level for 2dRMS is 95 percent. A third accuracy specification is circular error probable (CEP), which has a 50 percent 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. **Figure 6** shows the graph of varying HRMS 63 percent accuracy.

From **Table 1 and Figure 6** it can be seen that the HRMS 63 percent accuracy on the forest roads increases to as much as 41 m for the Scania data and approximately 27 m for the Iveco. The data for the public roads proves much more favorable with accuracy values of 2.55 m for the Iveco and 2.47 m calculated for the Scania. Results show that while the GPS accuracy varies considerably between public road data and forest road data, (thus emphasizing the effects of forest canopy) the tracking systems still work adequately to the point where the user can still monitor the movements of the trucks in real-time without the loss of much GPS and GPRS signal within the boundaries of the forests. From **Table 1**, results are comparable for both truck movements across the public roads. Accuracy results for the public routes prove compatible with other studies of a similar nature by Devlin et al. (2007b), where GPS accuracy was reported approximately between 10 m and 5 m. As mentioned previously, results of the trucks travelling in the forest vary at worst from 41 m for the Scania and 27 m for the Iveco. The reasons for the difference is related to the position of the GPS receiver, but more importantly, it is due to the varying and increased canopy of the forest from which the Scania truck was

transporting. Forest canopy has been well documented to affect GPS performance and accuracy but for this project the authors were not attempting to define a correlation between density of forest canopy and GPS accuracy. The assumption of signal degradation is based on visual inspection within the forest.

Recent developments in forest inventory GIS data include the X and Y coordinates of all of the entry and exit points for all of the Coillte forest boundaries. With the advancements of in-car satellite navigation systems, it could be possible to incorporate satellite navigation into the cab of the truck for the drivers to use. This implies sending routing information from the transport manager's computer in real-time to the truck's satellite navigation. Information that the Garmin Nuvi 770 can process includes X and Y coordinates of all of the entry and exit points of forest harvesting areas. If the X and Y locations of the in-forest timber stacks to be transported are also known, then the Garmin Nuvi could be used to route the truck beyond the entry point of the forest boundary and directly to the location of the timber stack for a more complete routing scenario.

Conclusion

The results of the field work prove that HRMS 63 percent accuracy does indeed become degraded under the forest canopy. But, the important thing to note in relation to the asset tracking systems is that the systems work well from a monitoring point of view. The GPS signal is still tracking the truck in-forest, and the user can monitor movements remotely from a computer browser within the forest, which is what is required. It would be a different situation if the signal were being lost and no position fixes were being acquired. The effect of the forest canopy reduced the eventual HRMS accuracy of the recorded values as much as 27 m and 41 m for the Iveco and Scania, respectively. It is the author's opinion that this accuracy in forest conditions is not good enough for pinpoint location of timber stacks to be transported (Holden et al. 2001, Spruce et al. 1993). With this accuracy information in mind, possible advancements as discussed, with routing trucks to timber stockpiles in the forest using satellite navigation becomes severely hampered and could in fact lead to a less than optimal route schedule. Accuracies of the value of 27 m and 41 m could imply looking for stock piles located in a harvested area as opposed to a road side position, which would be the original recorded X and Y coordinate. From a visual display purpose, the accuracy is related to the location of the GPS receiver which is in the front dashboard of the truck's cab and not external to the cab for operational reasons and security reasons as some transport managers do not want their drivers to know they are being GPS tracked and their working day monitored. These real-time GPS systems are being used to monitor actual truck driving time versus the actual working hours of the driver so that any discrepancies between claimed working hours and actual working hours can be settled relative to the driver's wages and thus a possible reduction in running costs. But, with the continuing development of the new European GPS satellite system, Galileo, and use of EGNOS (European Geostationary Navigation Overlay Service), it is hoped that greater precision and accuracy will be obtained under difficult canopy conditions and higher altitudes in the near future.

Within the Irish forestry sector, attempts are in progress to fully optimize the transportation of timber from forest harvesting site to sawmill, based on route and destination planning incorporating GIS and GPS technology. In an environment in which operating costs such as diesel fuel and labor are rising continuously, the timber haulage sector must implement the existing technology in order to remain competitive and maximize the time a truck is travelling while loaded in order to maximize revenue per load.

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